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Improving safety of interfactory and company motor and electric vehicles by introducing modern digital devices

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Introduction. Industrial injuries are one of the most pressing problems in the field of occupational safety at enterprises of the main industries in the Russian Federation. Most cases of such injuries are noted when moving goods and people by means of various types of interfactory transport. A set of regulatory documents developed in recent years by the Government of the country is dedicated to solving this problem. In accordance with the current trends in the development of new technical solutions, the use of a complex of devices based on IT-technologies is effective. This article is devoted to improving the safety of interfactory and company motor and electric vehicles by introducing modern digital devices.

Problem Statement. Almost all large industrial enterprises have a need to move goods and personnel both to the place of production activities and within the enterprises. Motor and electric vehicles used for these purposes do not always undergo a maintenance check, they often undergo technical inspection and repairs with whatever funds remains, and always the personnel operating these vehicles do not have permission to drive. Possible accidents with interfactory and company vehicles occurring as a result of insufficient control over the technical condition of vehicles and inadequate or absent medical and administrative checks of the operating personnel can lead to injuries at the enterprise.

Theoretical Part. This article proposes methods for reducing traffic accidents of interfactory and company motor and electric vehicles of industrial enterprises and warehouse enterprises through the introduction of remote monitoring of operation based on IT-technologies, operating with the use of mobile applications that use Internet of Things technologies. The options for introducing security elements designed to reduce the number of transport accidents in internal transport of industrial enterprises and warehouse complexes are considered. An experiment was carried out to introduce system components to vehicles of an industrial enterprise.

Conclusion. The use of the proposed monitoring and control system for motor and electric vehicles at machine-building enterprises and warehouse complexes will make it possible to quickly resolve issues related to labor protection, the economy of the enterprise and compliance with the labor discipline. In particular, it is planned to reduce vehicle failures due to mechanical failures, as well as to make timely decisions on the removal from driving the drivers who are not feeling well.

Keywords: interfactory transport, injuries, industrial accidents, vehicle monitoring, traffic accidents, occupational risk, sensors and tracking systems.

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Introduction. The Government of the Russian Federation issued Decree No. 833-r of 26.04.2019, which defines measures aimed at reducing the incidence of occupational injuries and bringing the result to the level of economically developed countries, encouraging employers and employees to improve working conditions and preserve the health of employees.

The set of measures includes four sections:

- improvement of mechanisms for preventing occupational injuries and occupational morbidity;
- encouraging employers and employees to improve working conditions and preserve the health of employees;
- motivating citizens to lead a healthy lifestyle;
- monitoring activities [1].

The adoption of this set of measures allowed the Ministry of Labor and Social Protection of the Russian Federation to draw certain conclusions already at the end of 2019.

In 2019, there was a certain movement towards reducing the level of occupational injuries. According to the data obtained, the number of group accidents, as well as cases with serious and fatal outcomes decreased: in 11 months of 2019, 4,078 accidents with serious consequences occurred, which is 9% lower than in the same period of 2018 (4,479 cases).

In 2019, there was a decrease in the number of deaths at industrial enterprises: in 11 months of 2019, employees died by 12% less than in the same period of 2018 (1,018 and 1,158 people, respectively).

However, the death toll in engineering, construction, and transportation is still high compared to other economic activities.

Problem Statement. In order to reduce the indicators of industrial injuries in interfactory and company vehicles, the authors have developed a system for monitoring and controlling safety in road transport in mechanical engineering. At enterprises, motor and electric transport is one of the priority areas of the production process. Industrial road transport is used for transportation within enterprises, as well as external transportation from enterprises to the nearest railway stations, ports, airports and supplier enterprises. Passenger motor transport is also widely used, designed to deliver workers to the place of employment. Road transport, in comparison with rail, cable, pipeline and other types of transport, is characterized by maneuverability and the absence of the need for the construction of complex engineering structures. This makes it possible to carry out cargo and passenger turnover within the districts and nodes directly from the shop (warehouse) of the supplier enterprise to the shop (warehouse) of the recipient enterprise without additional transshipment operations.

Vehicles operating both outside and inside the enterprise are an integral part of the production process. Various vehicles, both general-purpose and special-purpose, are used to perform technological and passenger transportation within production enterprises. In particular, fork loaders, bucket loaders, electric cars, automobile and electric tractors with trailers have become very popular.

However, as the number of vehicles increases, so does the risk of personal injury. Occupational risk is the probability of harm to the health of an employee as a result of exposure to a harmful and (or) dangerous industrial factor in the performance of the work function, taking into account the possible severity of the damage to health (the definition is given in accordance with draft Federal Law No. 1070354-7 "On Amendments to the Labor Code of the Russian Federation in terms of improving mechanisms for preventing occupational injuries and occupational morbidity" of December 07, 2020) [2]. Injuries resulting from road traffic accidents are the most common among accidents [3].

Now, not enough attention is given to monitoring of interfactory transport in mechanical engineering. In order to reduce costs, many large enterprises have disbanded internal road safety services, the technical control of vehicles is not carried out in accordance with the regulations and operating instructions, control over the health of drivers of interfactory transport is also not conducted (including checks for alcohol intoxication). All this increases the risk of accidents.

The draft Federal Law (draft No. 1070354-7) contains the following definition of occupational risk management. It is a set of interrelated measures and procedures that are elements of the occupational health and safety management system and include the identification of hazards, assessment of occupational risks and the application of measures to reduce the levels of occupational risks or prevent their increase, monitoring and review of the identified occupational risks. Based on this definition, the authors developed a system that uses remote control (monitoring) based on digital information technology systems and operates using mobile applications.

Theoretical Part. The reduction of risk in the movement of interfactory transport is as follows — it is proposed to implement a project on the introduction of digital electronic devices that work in two directions. The first direction is monitoring the performance of routine maintenance work on transport, including daily technical inspections, daily medical examinations of drivers with possible vehicle blocking if the parameters exceed critical values. The second direction is the use of real-time transport monitoring systems that monitor the health status of drivers of

industrial transport both inside and outside the enterprise, compliance with Traffic rules, the technical condition of cars and other transport units, the microclimate in the workplace, as well as the introduction of a system for warning personnel about the approach of a vehicle.

The developed system makes it possible to unify and systematize the requirements of supervisory authorities for construction equipment, machine operation, and technological equipment, and makes it possible to make recommendations based on objective data taken at the site, improving the quality and transparency of the work of state regulatory services [4].

Implementation of the project is possible both on cars of machine-building enterprises used on public roads (cars, trucks, buses), and on interfactory vehicles (loaders, electric cars, tractors).

The proposed system composition. Elements of the first direction. A key chip reader/writer with a prescribed daily code consisting of the data of the equipment manager, medical worker and the dispatcher of the enterprise is loaded in a personal computer. The key chip is a common USB flash drive. The code of the equipment manager is the data on the technical inspection of vehicles, the time and order of routine maintenance, the validity period of the certificate of insurance of compulsory civil liability insurance or the policy of voluntary insurance against damage or theft (depending on where the vehicle is operated). The code of the medical worker is formed from the data of the daily medical examination of the driver. The codes of both specialists are recorded by the dispatcher of the enterprise in the chip key of the driver or operator of the self-propelled car. The daily code of the equipment operator is also registered via a Wi-Fi in the memory of the digital mini-computer installed on the vehicle. In addition, the dispatcher records the unique data of the vehicle in the driver's chip key, which will be used to remove the lock on starting the engine. If the key chip does not have any data from one of these specialists, the vehicle will be unusable. The codes of the medical worker and the dispatcher are also transmitted via coded means of wireless communication to the mini-computer of the vehicle.

A mini-computer is an electronic device in the form of a digital-to-analog converter that performs an algorithm for checking codes from a USB key and codes received via wireless communication systems. If the codes match, an analog command is sent to close the ignition switch or starter switch (depending on the vehicle design). The mini-computer does not require serious and expensive installation; it is performed by a specialist in automotive electrical equipment. The installation of this system does not require approval from the traffic police, because it is not a conversion of the vehicle.

An additional positive feature of the proposed system for vehicles operated outside the enterprise is the anti-theft functions.

Elements of the second direction. The head unit that works with all types of sensors is the GPS/GLONASS monitoring module, hereinafter referred to as the master module (Fig. 1).

Such modules have extensive configuration and programming capabilities [5].

The main task of the module is to transmit data about the location of the vehicle, its speed of movement at a certain moment. By means of the built-in SIM cards, the module can transmit and receive a large amount of information. In particular, it can be used to monitor the compliance with Traffic Rules, namely the speed limit and the deviation from the requirements of road signs [6].



Fig. 1. Master module based on GPS/GLONASS monitoring device

The second necessary device is a module for monitoring the driver's well-being. The principle of operation of such devices is different — the data come from the built-in cameras monitoring the driver's eyes (Attention Assist system — Germany, Driver Alert Control — Sweden, Seeing Machine system — UK), or it uses the bracelet and the ring that controls body temperature (Vigiton system — Russia (Fig. 2) [7].



Fig. 2. Vigiton System

The control over the technical condition of the vehicle is assigned to the module built into the dashboard of modern cars. The data on critical values of various parameters are transmitted via the CAN bus and can be processed and transmitted via the GPS/GLONASS monitoring module to the enterprise server, where the settings will either signal the dispatcher and the chief mechanic to personal mobile devices, or block the fuel supply to the vehicle [8].

The microclimate in the workplace has a serious impact on the well-being of the driver of the vehicle. A comfortable temperature must be observed in the car interior for high productivity. For its control, either standard built-in cabin temperature sensors are used, or additional ones are installed. The information from them is also transmitted via the CAN bus or via an analog-to-digital converter to the master module, through which, in turn, it is transmitted to the server.

An important factor affecting the fatigue of drivers and operators of self-propelled vehicles is carbon monoxide. This factor is especially important in large indoor production facilities, where several loaders can work

simultaneously, equipped with internal combustion engines [9]. The amount of carbon monoxide (CO₂) is proposed to be estimated by gas analyzer sensors, the data on exceeding critical readings of which are also transmitted to the dispatchers for making appropriate decisions (Fig. 3).



Fig. 3. Carbon monoxide sensor

Injuries in poor lighting of the workplace are quite frequent cases. Many machine-building enterprises operate around the clock, which forces interfactory transport to work in the dark. Failure of the lighting lamps or parking lights can also have a negative impact on the injury situation. To monitor the serviceability of the lighting equipment, it is proposed to introduce a lamp-monitoring module that determines the fault by the drop in current consumed by the lighting lamps [10].

The authors also suggest that when moving goods that reduce visibility to the driver or operator, the ZoneSafe Compact sensor module should be implemented on the vehicle, which reduces the risk associated with vehicles at the enterprise [11]. The module automatically detects the presence of any person or vehicle within a radius of up to eight meters from the vehicle and turns on the light signal for all objects within the range of this module (Fig. 4).



Fig. 4. ZoneSafe operation principle

Research Results. Currently, an experiment has been conducted to implement this system on Lada Kalina and Lada Largus cars of one of the production enterprises of the Rostov region. The installation of the system on cars has revealed the following features: when using the CAN bus in cars, the installation of the system requires less effort due to the more extensive functionality for transmitting information from the built-in engine control unit, as well as the presence of a large number of built-in electronic components, such as outdoor lighting control units or distance detection modules. For interfactory transport the installation of this system requires the implementation of a certain number of analog-to-digital converters that will convert the analog signal to the engine overheating, including, for example, the control lamp on the dashboard, to a digital signal for transmission through the master module in the mobile device of the dispatcher and the chief engineer. At the time of the experiment, the screen of the enterprise dispatcher's tablet looked like this (Fig. 5).

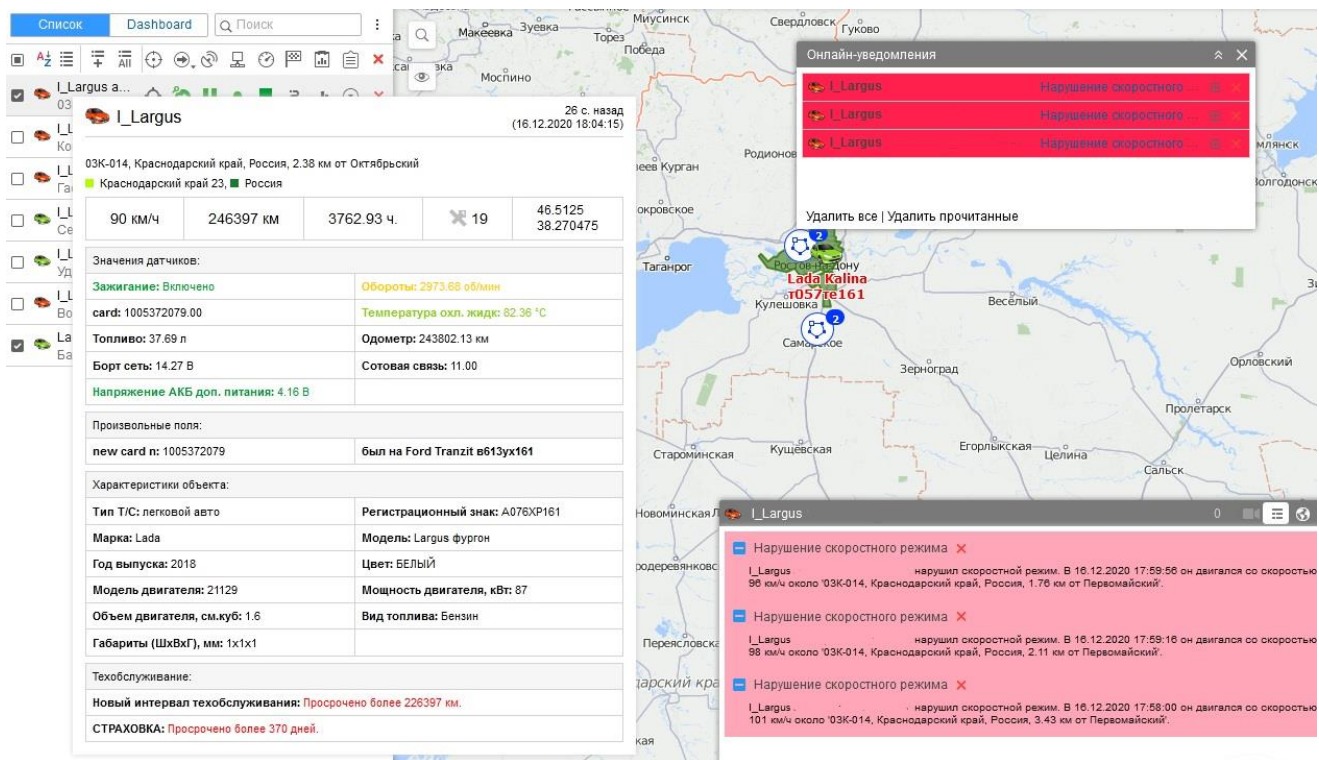


Fig. 5. The tablet panel of the motor transport enterprise dispatcher

This picture shows that the driver of the Largus car violated the speed limit, the car is overdue for maintenance and the insurance policy is overdue for a year.

A certain disadvantage in the operation of the system is associated with the use of the GSM network as a data transmitter. In places where there is no coverage of this network, there may be problems with the information transmission. However, when the signal appears, all information is transmitted in a single packet for the entire time that the vehicle was out of the network coverage area. If the company is located outside the mobile operators signal range, you can use the company's Wi-Fi network (with a certain upgrade of the master module).

Conclusion. The use of devices for monitoring and controlling company and interfactory transport at machine-building enterprises will allow us to quickly solve issues related to labor protection, the economy of the enterprise and the compliance with labor discipline. In particular, operational monitoring of the technical condition of the vehicle at a given time, signaling to the dispatcher's console about the fact that the controlled parameters exceed critical values and timely taken measures in this regard will prevent traffic accidents. Also, the monitoring system, which is being developed, will not allow faulty vehicles operation, and will not allow non-accredited personnel and unauthorized persons to drive. The presented system, in addition to machine-building enterprises, can be implemented at large warehouse complexes, logistics enterprises, and airports.

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A. A. Korotkiy — scientific supervision, analysis of the research results, revision of the text, correction of the conclusions; O. A. Bakhteev — formulation of the main concept, goals and objectives of the study, conducting experiments; S. S. Kostyukov — preparation of the text, formulation of the conclusions.

Finite element analysis of microclimate parameters in the metallurgical crane cabin

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Introduction. The article analyzes the microclimate parameters (temperature, speed and air pressure) in the metallurgical crane cabin provided by the air conditioning system using the finite element method integrated into the ANSYS software package. The metallurgical crane cabin air conditioning system was selected based on the engineering calculation of the required air flow rate supply, taking into account factors that affect the system performance, such as the location of the equipment and the degree of its dustiness.

Problem Statement. The purpose of this research was to check the efficiency of the air conditioning system of the metallurgical crane cabin, which was selected based on the results of the engineering calculations.

Theoretical Part. In the main part of the research, the distribution fields of temperature, speed and air pressure inside the cabin of a metallurgical crane were constructed, the values at the points of which were compared with the hygienic standards. In addition, the factors that affect the adequacy of the developed model were considered, namely the grid structure, the way to set the initial and boundary conditions.

Conclusion. The refinement of the analysis grid and the consideration of infiltration in the model eventually allowed us to get more correct results: the temperature at the characteristic points differ by no more than 1.3 °C, the speed values do not exceed the standard 0.3 m/s, the average normalized temperature of 24 °C is maintained in a volume of about 60-70 % of the total cabin volume.

Keywords: metallurgical crane cabin, air conditioning, microclimate parameters, finite element analysis.

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Introduction. The working conditions of operators of technological and mobile machines are often characterized by high values of microclimate indicators, namely, temperature and intensity of thermal radiation. Affecting the employee, they can lead to a decrease in physical performance, the occurrence of colds and, after a year of work, occupational diseases of the cardiovascular and respiratory systems [1, 2].

To prevent cases of occupational diseases among employees of industries that are harmful in terms of microclimate parameters, such means of thermal protection of workplaces are necessary, the effectiveness of which is subject to the heightened requirements, for example, air conditioning systems.

Problem Statement. Many operating factors often remain unaccounted for in the calculation and selection of the air conditioning system of technological and mobile machines: dustiness of air and equipment, length and layout of the air conditioning system. In addition, it is also important to assess the extreme boundary weather conditions of the environment in which the machines can be operated. All this makes it possible to predict a possible decrease in the performance of the selected system during operation and to exclude a negative impact on the employee [3–5].

In this research, the task is to check the efficiency of the air conditioning system of the metallurgical crane cabin, for which its main characteristics were determined — the supply air consumption and cooling capacity. These characteristics include a correction factor that takes into account the pressure loss in the alignment lines, the way the internal and external unit of the system is located, as well as their contamination. The efficiency check is performed by constructing the temperature, speed, and air pressure fields inside the metallurgical crane cabin in the ANSYS software package.

The object of the study was the cabin of a metallurgical crane operated on the site of an arc steelmaking furnace (ASF) of an electric steelmaking shop.

Theoretical part. Construction of the calculation area. Based on the design three-dimensional model of the cabin in CAD, the design area was developed (Fig. 1). In the course of the work, the geometry of the cabin was slightly

simplified; elements that slightly affect the general nature of the gas dynamics processes and obtaining the thermodynamic parameters of the model were excluded. Complex (small and saber-shaped) surface elements, edges, and gaps between surfaces were excluded from the geometry [6, 7].

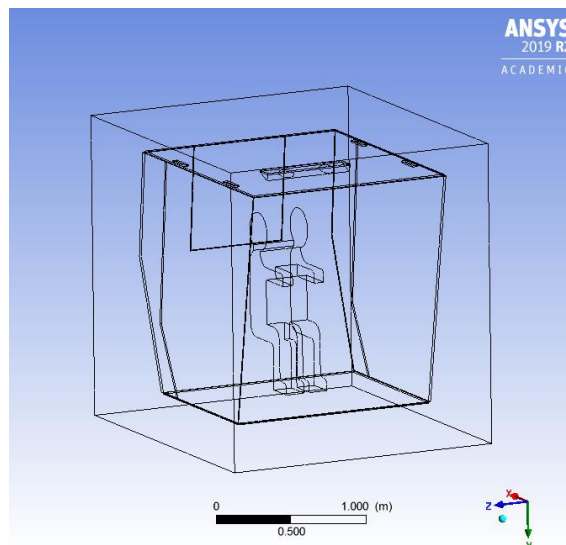


Fig. 1. Calculation area of the metallurgical crane cabin (front view)

The heat transfer through the multi-layer enclosure of the cabin, which affects the total heat flows, which were calculated using engineering techniques (from the heat balance of the cabin) and which were no more than 30 % of all heat flows, was taken into account by setting the thermal contact resistance in ANSYS. This coefficient integrates the values of the difference in temperature, thickness, and heat transfer coefficients between heterogeneous layers of fences, as well as heat flows.

Calculation Grid. The comparative calculation of the processes was carried out with a different grid structure: coarse — at the wall zone (the size of the elements — 0.15 m) (Fig. 2 a) and fine (the size of the elements — 0.025 m) (Fig. 2 b).

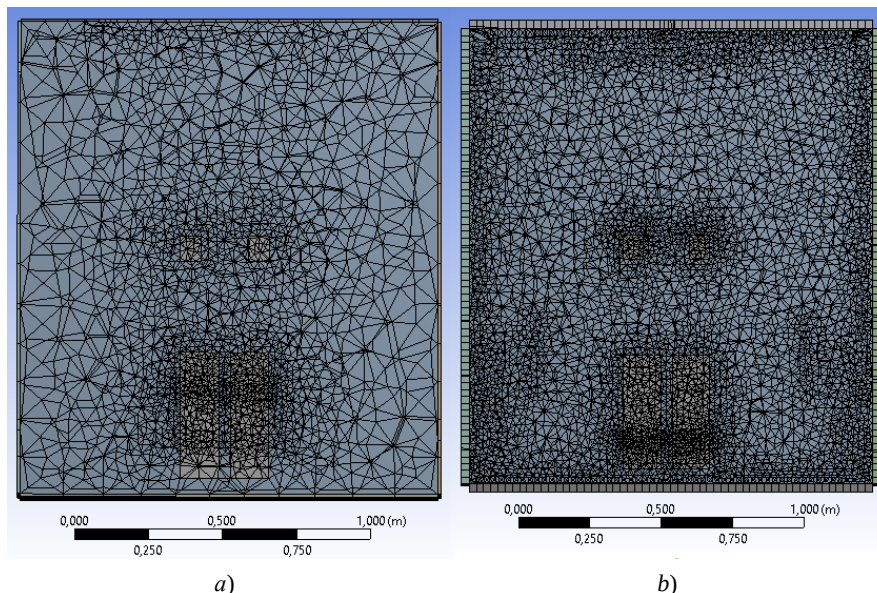


Fig. 2. Calculation grid: a — coarse; b — fine

Set initial and boundary conditions. As other boundary conditions, the temperatures on the wall surface and the flow rates of the air supplied to the cabin, determined on the basis of engineering techniques, were used.

Table 1 shows the boundary conditions of the model. Heat input from sources of heat radiation on the ASF area were further set for some of the walls.

Table 1

Boundary conditions of the model

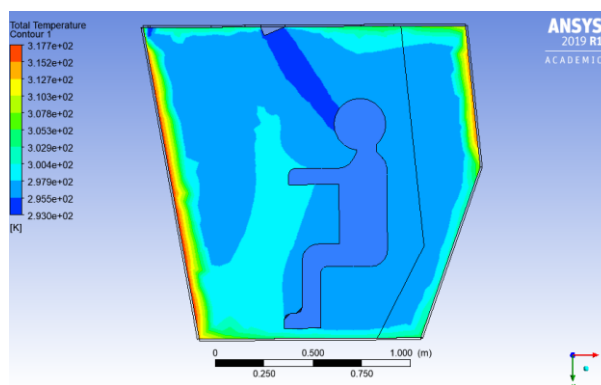
No.	Wall type	Boundary conditions			
		Ambient air temperature, °C	Heat input from the wall, W/m ²	Heat input from heat radiation sources, W/m ²	Thermal contact resistance, m ² ·K/W
1	Front wall	38.35	210	1445	0,11
2	Side walls		104	951	0,09
3	Upper wal		177	—	0,2
4	Rear wall		59	—	0,19
5	Floor		54	1705	0,32

Results of modeling of heat and mass transfer in the cabin of a metallurgical crane (coarse grid of 0.15 m). The mathematical model of heat and mass transfer and the calculation of thermodynamic parameters and air flow mobility in the cabin of a metallurgical crane, performed in the ANSYS software package, on the one hand, allows us to clarify a detailed picture of the distribution of thermodynamic parameters in the cabin (temperature fields and air movement), and on the other — to consider the problem of determining pressure fields, the values of which have certain operational requirements. According to the performance requirements of the ventilation system, it should be sufficient to provide excess pressure in the combine cabin in the range of 50–200 Pa, taking into account air exchange with the external environment.

The calculation of air flow and thermodynamics in the unified cabin of grain and feed harvesters was modeled using the FluidFlow plug-in module (CFX). For this case, a more accurate model of turbulence was chosen — Shear Stress Transport (SST), which provides adequate behavior of the model equations in both the near-and far-field zones. This is due to the fact that the SST model uses the $k-\omega$ model to calculate the boundary layer, and the $k-\varepsilon$ model to calculate the flow core at a distance from the walls. This, in fact, is the advantage of this turbulence model. The disadvantage can only be an overestimation of the level of turbulence in areas with high accelerations or in stagnant zones, which is not typical for this case [8, 9].

The SST model is described by equations similar to those of the standard $k-\omega$ model. The solution to the equations allowed us to obtain pictures of the distributions of the temperature, velocity, and pressure fields at the operator's workplace.

Figure 3 shows the calculated temperature distribution fields in the cabin relative to the deflectors and the operator (in different planes), Figure 4 shows the air velocity distribution fields in the cabin, and Figure 5 shows the pressure distribution fields in the cabin.



a)

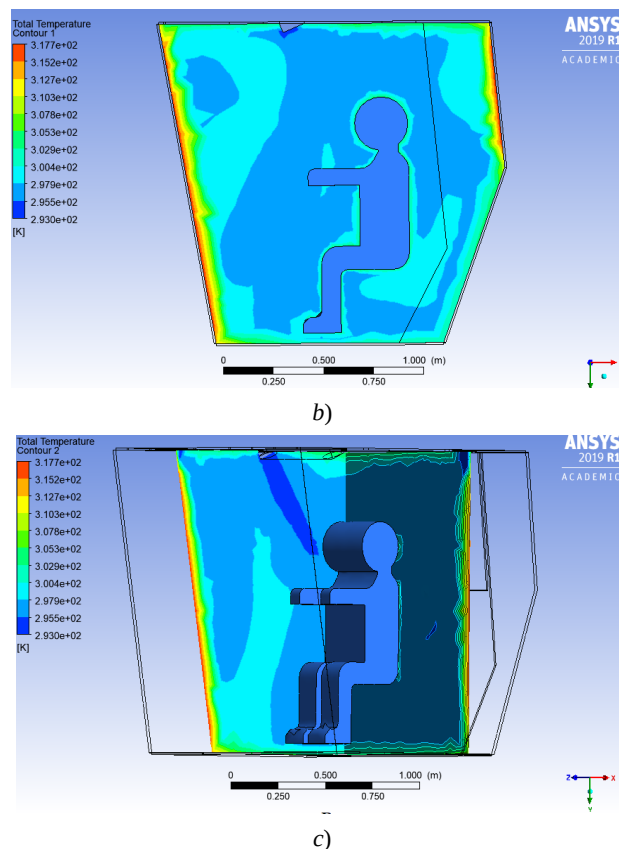
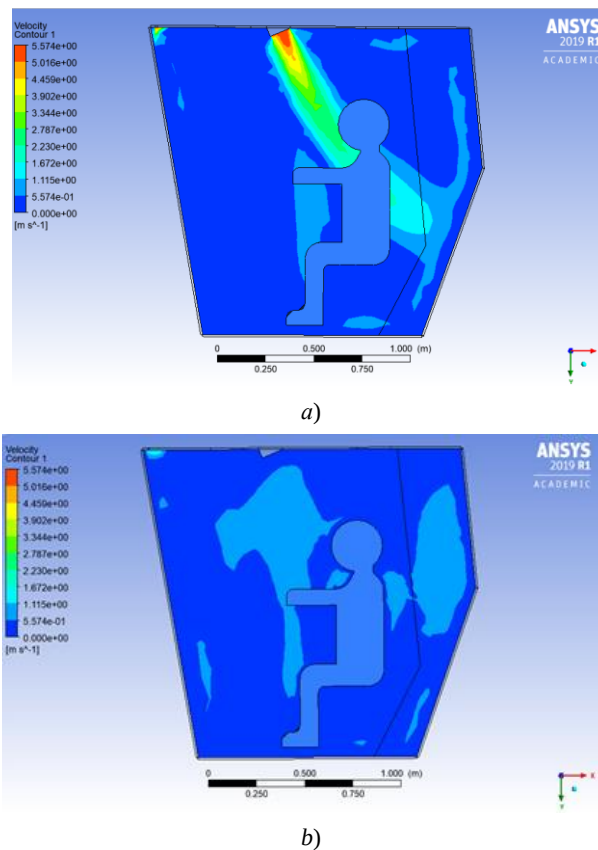
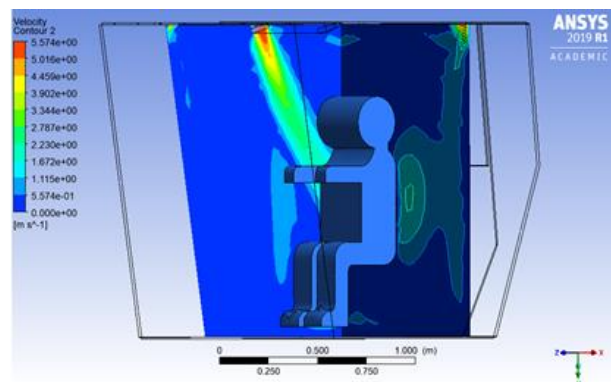


Fig. 3. Temperature distribution in the cabin of the metallurgical crane: a — relative to the deflectors (in the two-dimensional plane); b — relative to the operator (in the two-dimensional plane); c — relative to the deflectors (in the three-dimensional plane)

Based on the obtained results of constructing the temperature fields in the cabin (Fig. 3), the following conclusion can be drawn: the flow rate of air supplied to the cabin ($680 \text{ m}^3/\text{h}$) with a given temperature (293 K or 20°C) determined by engineering methods will be sufficient to ensure the temperature in the cabin corresponding to the permissible class of working conditions 2 (297 K or 24°C). Therefore, the employee will not be adversely affected.

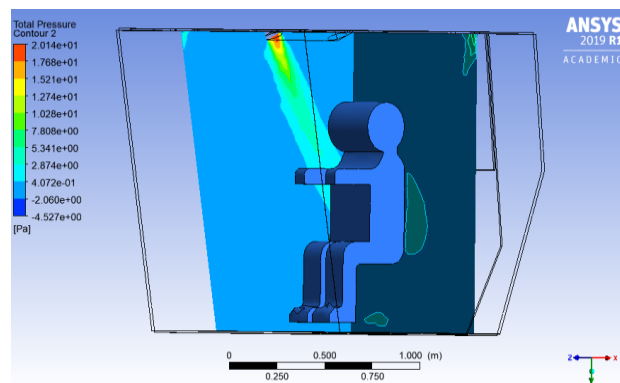




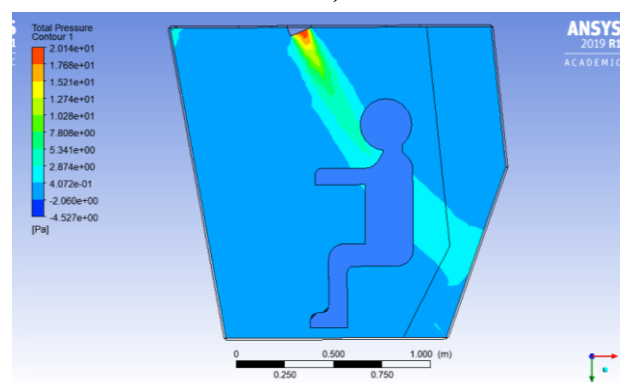
c)

Fig. 4. Distribution of air velocities in the cabin: a — relative to the deflectors (in the two-dimensional plane);
b — relative to the operator (in the two-dimensional plane); c — relative to the deflectors (in the three-dimensional plane)

Based on the results of building the fields of velocities in the cabin (Fig. 4), we can conclude the following: in certain engineering methods consumption supplied to the cabin air, the speed of air movement in the vicinity of the operator will be from 0.56 to 1.12 m/s, which exceeds the sanitary-hygienic standard set for acceptable working conditions (0.1–0.2 m/s). Therefore, the employee may have colds.



a)



b)

Fig. 5. Pressure distribution in the cabin: a — relative to the deflectors (in the three-dimensional plane);
b — relative to the deflectors (in the two-dimensional plane)

Based on the obtained results of constructing the pressure fields in the cabin (Fig. 5), the following conclusion can be drawn: the pressure in the flow of air supplied to the cabin at a flow rate determined by engineering methods is on average 2.87 Pa, which is presumably enough to achieve a pressure in the cabin greater than 50 Pa after the 15 minutes of the experiment. Unfortunately, with this approach, the ANSYS FluidFlow (CFX) tools do not construct a picture of a uniform distribution of pressure in a closed space when air is supplied inside. It is only possible to display the pressure in the supply air flow.

Model verification (coarse grid of 0.15 m). The ambient air temperature is measured at points 1–7 (Fig. 6) or at the points closest to them. It is recommended to measure the air velocity at a point at the operator's eye level (point 7 in Fig. 6) [10].

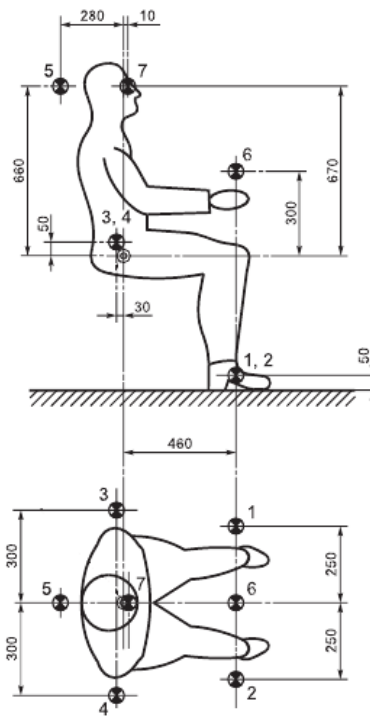
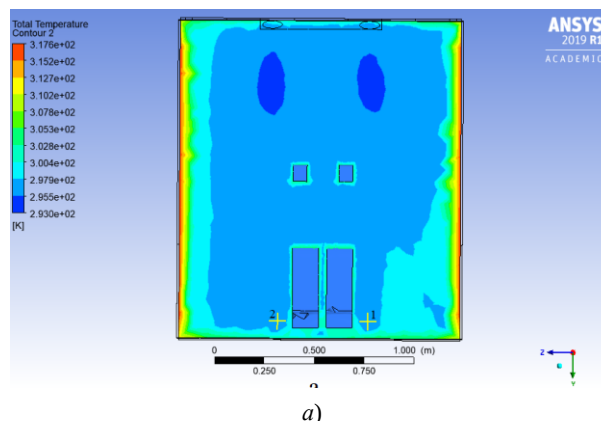


Fig. 6. Location of measurement points

General minimum operating characteristics:

- measurement results of the temperature of the operator's surrounding space should not differ by more than 5°C in all modes of air conditioning, heating or ventilation;
- it is recommended that the maximum air velocity in front of the operator's eyes (position 7 in Fig. 6) does not exceed 0.3 m/s.

Figures 7 and 8 show the calculations results of the values of temperature and air velocity.



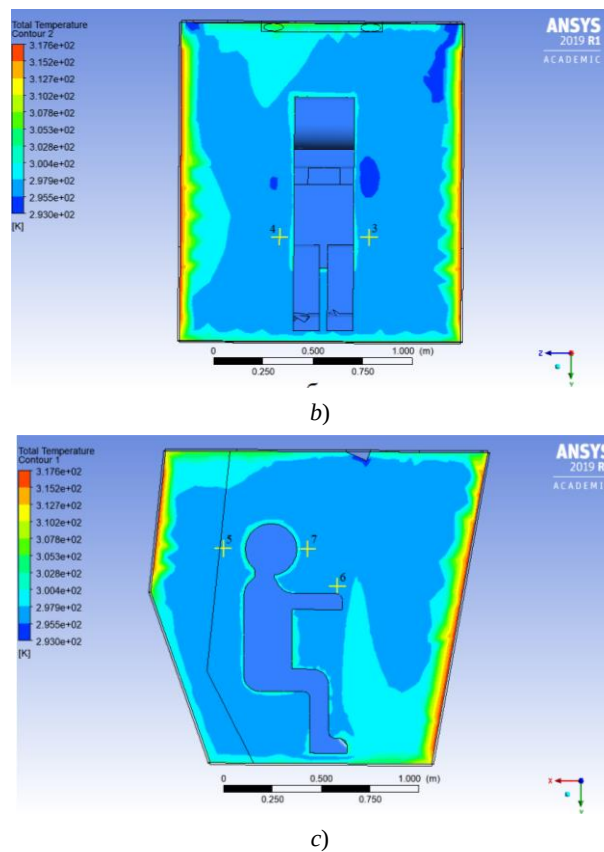


Fig. 7. Results of temperature calculations:
a — at points 1, 2; b — at points 3, 4; c — at points 5, 6 and 7

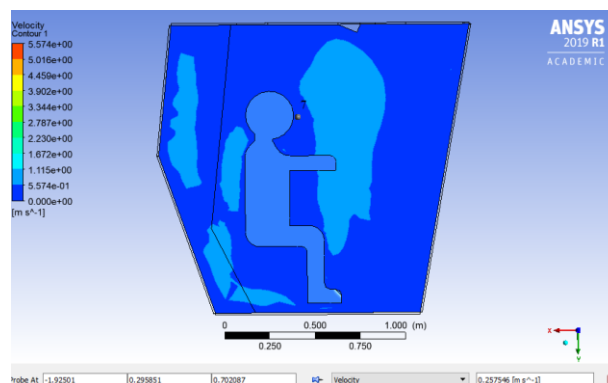


Fig. 8. The results of calculations of air velocity at point 7

As it can be seen from the measurement results, the temperature at all points is the same (297 K or 24°C), and the speed at point 7 does not exceed 0.3 m/s. Therefore, we can talk about the correctness of the calculated parameters of the air conditioner and the model as a whole in terms of achieving the required temperature and air velocity.

Verification of the model (fine grid of 0.025 m). The following changes were made to the fine-grid model:

- 1) The calculation was performed in the ANSYS 2019 R3 program.
 - 2) The size of the grid cells was changed from 0.13 m to 0.025 m, resulting in a total calculation time of 1 hour. In addition, the density of cells in the wall area is increased to refine the results of the heat transfer process through the wall.
 - 3) The outflow of air from the cabin was set in a calculated way, taking into account the number of heat flows per infiltrated air. The flow rate of the infiltrated air calculated in this way was the boundary condition for the "Outlet" boundary.
 - 4) The thermal resistance coefficient of the fence layers in the interfaces is taken into account.
- The calculation results of temperature and velocity values are shown in Fig. 9–10.

As it can be seen from the results of the calculations, the average temperature in the cabin in the overwhelming volume of its space is up to 70 % the same (297 K or 24°C), which indicates a weak influence (0.2–0.5°C) of a smaller grid on the final results of the calculation as a whole. The speed at point 7 does not exceed the standard 0.3 m/s.

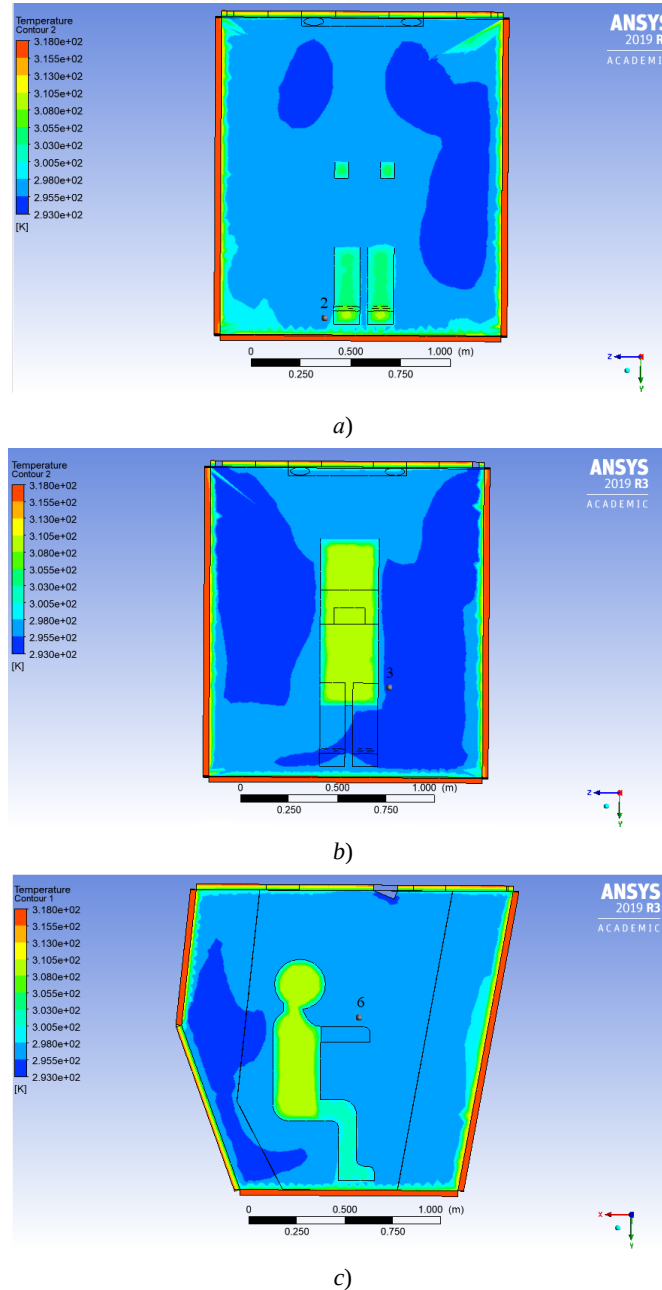


Fig. 9. Results of temperature calculations: a — at point 2; b — at point 3; c — at point 6

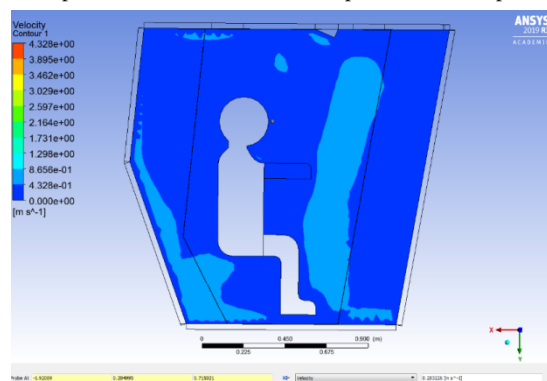


Fig. 10. Results of speed calculations at point 7

Comparison of the results of model calculations with experimental data. The results of the experiment are taken from the special assessment of working conditions of the driver (Taganrog Iron & Steel Factory (TAGMET)):

- 1) The ambient temperature during testing — 39.4°C.
- 2) The maximum difference between the average air temperature in the cabin and the ambient temperature is 15.7°C.
- 3) Humidity in the cabin — 27 % (outside 15 %).
- 4) The established average temperature in the cabin — 24.6°C.

The results of the model calculations are shown in Fig. 11.

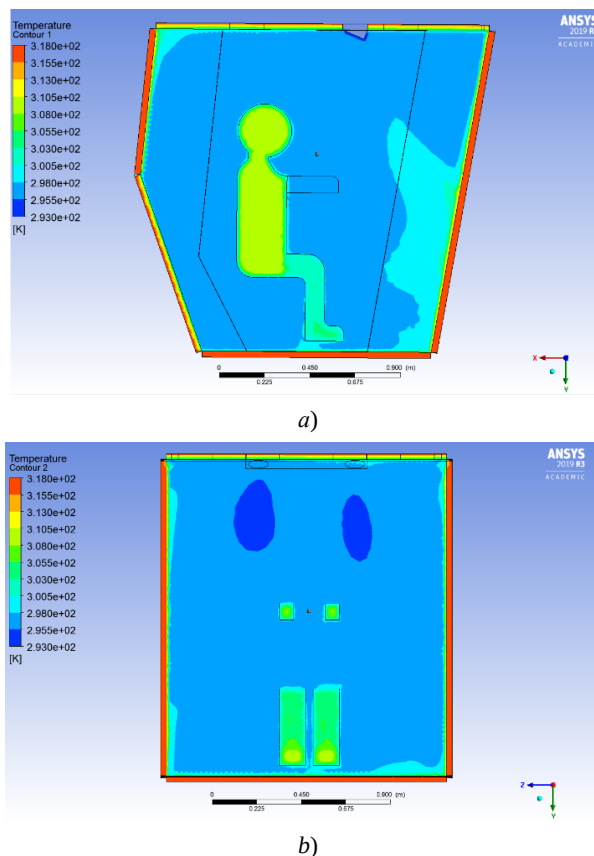


Fig. 11. Average cabin temperature: a — side view; b — front view

Based on the results of the model calculations, it can be concluded that the discrepancy between the experimental and model values is no more than 0.16°C. This fact gives the right to speak about the adequacy of the created model in terms of achieving the required temperature and air velocity.

Conclusion. The refinement of the calculated grid and taking into account the infiltration in the model, ultimately, allowed us to get more correct results: the temperatures at the characteristic points differ by no more than 1.3°C, the speed values do not exceed the standard 0.3 m/s, the average normalized temperature of 24°C is maintained in a volume that is about 60-70% of the total volume of the cabin. As for ensuring the necessary air pressure in the cabin of the metallurgical crane, with this approach, the ANSYS FluidFlow (CFX) tools do not assume the construction of a picture of a uniform distribution of pressure in a closed space when air is supplied from inside. It is only possible to display the pressure in the supply air flow. The solution to this problem is possible with a more careful adjustment of the boundary conditions of the model.

In general, the finite element analysis allows us to solve a rather important problem from the point of view of industrial safety — preventing a decrease in the performance of the air conditioning system by rational selection of the equipment at the design and forecasting stage, as well as achieving microclimate parameters due to this.

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Contribution of the authors:

V. V. Maslensky — calculations, text preparation, analysis of the results of the study, formulation of the conclusions; Yu. I. Bulygin — formulation of the main concept, goals and objectives of the study, finalization of the text, conclusions correction.

Training modules in the formation of risk-based thinking of employees in oil industry

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Kalashnikov Izhevsk State Technical University (Izhevsk, Russian Federation)

Introduction. The relevance of the presented work is, first of all, due to the significant number of employees of oil companies. There are more than a million of such specialists working in Russia. At the same time, world statistics claim that more than a third of critical deviations in the health indicators of workers are associated with harmful production factors. In order to avoid the relevant risks, it is important, in particular, to organize productive training in labor safety standards and rules, and to form risk-oriented thinking.

Problem Statement. The conducted research is aimed, first, at identifying typical occupational risks in the field of oil production. The Standard Regulation on the Occupational Health and Safety Management System developed by the Ministry of Labor of the Russian Federation is used as the basis for classification. Secondly, the features of modular training in labor safety standards and rules, taking into account the risks in the workplace, are justified.

Theoretical Part. The regulatory and legal framework of labor protection, including enterprises with high accident risks, is considered. The paper provides key professions and main labor functions taking into account the production practices of two oil-producing enterprises operating in Russia. The analysis of actual workplaces and regulatory documents allowed us to establish typical occupational risks for the specialties under consideration. The recommendations for improving the system of training in labor safety standards and rules are proposed.

Conclusion. Occupational risks are identified from the list of hazards presented in the Standard Regulation on the Occupational Health and Safety Management System. The recommendations for the implementation of the identified occupational risks in the system of training in occupational safety standards and rules are proposed. With this information, you can reduce the time spent on identifying occupational risks in oil production, which generally optimizes the risk management of this field.

Keywords: occupational safety, occupational risks, oil production, occupational risk management, training in occupational safety standards and rules.

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Introduction. According to the UN, accidents at work and occupational diseases cause the death of more than 2 million people a year ¹. At the same time, more than a third of critical deviations in the health indicators of workers are caused by harmful production factors [1]. The monitoring conducted at the beginning of the XXI century showed that the total number of injured people in the world exceeded 300 million [1].

Oil-production enterprises are located throughout the country, and the number of employees, including service organizations, exceeds one million. All this has led to the relevance of comprehensive research aimed at identifying occupational risks and their relationship to technological processes.

To prevent the implementation of occupational risks, training in occupational safety standards and rules is important. Technical measures can reduce, but not eliminate, the potential danger of the equipment used. In this case, the key control element will be the appropriate training of employees and specialists in the field of occupational risks and occupational safety. This approach can be called the formation of risk-based thinking.

Problem Statement. An important place in the production activities management is occupied by the professional risks management. The register containing the identified professional risks of employees is one of the local regulations of the organization that are subject to verification in the field of professional risk management².

¹ World Health Statistics 2020: monitoring health for the SDGs, sustainable developments goals / United Nations. URL: <https://www.who.int/data/gho/publications/world-health-statistics> (Accessed 15th January 2021).

² Ob utverzhdenii Metodicheskikh rekomendatsiy po proverke sozdaniya i obespecheniya funktsionirovaniya sistemy upravleniya okhranoy truda. Prikaz Rostruda ot 21.03.2019 No. 77. Ministerstvo truda i sotsial'noy zashchity Rossiyskoy Federatsii; Federal'naya sluzhba po trudu i zanyatosti [On the approval of Methodological recommendations for checking the creation and operation of the labor protection management system. Order of

The objectives of the presented work are to identify typical occupational risks in oil production, taking into account the Model Regulations³ published by the Ministry of Labor, and to develop proposals for improving the organization of training in labor safety standards and rules.

Theoretical Part. Identification of typical professional risks for people engaged in oil production was carried out at two enterprises: AO Belkamneft named after A. A. Volkov and Udmurtneft OAO.

Let us look at the key professions and the functionality of specialists working in this area.

— The oil and gas production operator maintains and ensures the smooth operation of the surface equipment of wells. His responsibilities also include the operation of automation that measures the parameters of the technological process and sampling [2].

— The operator of the desalting and dewatering plant controls the parameters of the technological process (temperature, pressure, flow), procedures for reducing the concentration of salts and water in oil, and is responsible for the operation of pumping, safety and heating equipment [3].

— The operator of the oil and gas production control panel provides start-up and shutdown of installations and mechanisms, information support and management of operators' work.

— The chemical analysis laboratory assistant uses chemical analysis methods to determine the current parameters of oil quality (composition, balance of chemical elements, impurities and compounds) [4, 5].

— The commodity operator controls the serviceability of the equipment of commodity and tank parks, level measurement and sampling of oil from tanks.

— The driller of workover of wells is responsible for capital repairs of wells with the use of special equipment [6, 7].

The classification of typical professional risks in the field of oil production is based on the nature of the impact source:

- mechanical hazards,
- electric danger,
- thermal danger,
- microclimate and climate,
- chemical factors,
- noise,
- vibration,
- aerosols (mainly fibrogenic),
- biological factor,
- physical overload and intensity of labor,
- impact of light,
- impact of plants,
- organizational shortcomings,
- fire,
- explosion,
- PPE,
- collapse,
- transport.

The identified typical occupational risks in oil production are described in more detail in [8].

Rostrud No. 77 of 21.03.2019. Ministry of Labor and Social Protection of the Russian Federation; Federal Service for Labor and Employment]. Available from: http://www.consultant.ru/document/cons_doc_LAW_322223/2ff7a8c72de3994f30496a0ccbb1ddafdaddf518/ (Accessed 16th January 2021).

³ Ob utverzhdenii Tipovogo polozheniya o sisteme upravleniya okhranoy truda. Prikaz Mintruda Rossii ot 19.08.2016 No. 438n. Ministerstvo truda i sotsial'noy zashchity Rossiiskoy Federatsii [On the approval of the Model Regulation on the labor protection management system. Order of the Ministry of Labor of the Russian Federation No. 438n of 19.08.2016. Ministry of Labor and Social Protection of the Russian Federation]. Available from: <https://mintrud.gov.ru/docs/mintrud/orders/541> (Accessed 16th January 2021).

The development of risk-oriented thinking of employees contributes to the reduction of the probability of professional risk realization. To do this, it is necessary to increase the effectiveness of training in labor safety standards and rules.

In such trainings, the activities related to risk management are modeled. This forms the basis for implementation of a process approach to risk accounting. Training materials created in the context of a risk-based approach should take into account the potential frequency and risk of hazards to the enterprise. When developing the risk register, the method of group expert assessments was used, which is traditionally a method of analyzing poorly formalized problems.

When selecting experts (all of them worked at the enterprises under study), their individual characteristics were taken into account: competence, creativity, attitude to expertise and constructive thinking. The expert group consisted of 7 people, including leading specialists of the labor protection department and managers of different levels. The expert assessment of the main risks was carried out using a questionnaire. The questionnaire consisted of 11 closed-type questions. The survey of experts allowed us to compile a risk register, which became the basis for the creation and implementation of a risk-based training program for employees of the enterprise.

The training was based on the Kolb's model (or cycle). This approach is based on the employee's work experience, so it is applied to adults who have professional experience.

The training program is proposed to be divided into relatively small modules, each of which would include 7-9 didactic units that are optimal for mastering. The training module should include theory, normative materials, and, if possible, visual and video materials. Typical occupational risks should be linked to the topic of the module.

As a rule, occupational safety is taught to adults, for whom training is not the main activity. This explains the special role of feedback with the audience.

At the first stage, the employee studies the theoretical material of the module. At the same time, it is important to use visual aids (including videos) that specify the theory and link it to the real work. In addition, the training should be based on their own practical experience, updating the production discourse.

The second stage is control. Two types of tests should be used here. Recent pedagogical studies confirm that it is not advisable to test a student more than twice. Students receive verbal support in the form of test tasks, so they are more willing to ask questions and work through difficult moments. Due to such communication, the teacher determines the level of mastering the material and fills in the information gaps.

When forming a bank of test tasks, it is necessary to focus on the taxonomy of Bloom's goals. The original goal taxonomy identifies 5 mental actions. Of these, knowledge comes first, and understanding comes second as a way to transform material from one form of expression to another. It is fundamentally important that the educational material is perceived at the level of understanding. This is what the tests should determine. We believe that it is inappropriate to require presentation of the material (level of knowledge) in such an audience.

Test number two completes the training cycle based on the materials of the module. In 98% of cases, students receive a positive rating on it, and this proves the effectiveness of the modular technology.

It should be noted that the identification of hazards in real workplaces gives more significant results in terms of reducing the likelihood of occupational risks. In this case, the typical occupational risks will serve as the basis for the formation of registers of identified occupational risks. Their inclusion in the training modules will contribute to a more active and effective formation of risk-based thinking.

Conclusion. Labor protection as a system of norms and measures is designed to regulate labor activity taking into account harmful and dangerous industrial factors, to ensure the reduction of the level of industrial injuries and the likelihood of emergencies. Workers engaged in oil production are affected by a large number of harmful factors. These are, for example, noise, vibration, high physical and psychoemotional loads. Among the dangerous factors, high-pressure equipment, explosive and flammable substances should be mentioned first of all [9].

To reduce the number of occupational injuries (accidents) and occupational diseases, a set of measures is needed, one of which is the assessment of occupational risks in the workplace. Within the framework of the presented study, the relevant procedures were carried out in relation to personnel employed in oil production, taking into account

the Standard Provision⁴ of the Ministry of Labor. Using the obtained data, it is possible to reduce the time spent on identifying professional risks in oil production, which generally optimizes the risk management of this area.

The modular system of training in occupational safety standards and rules will contribute to the formation of risk-based thinking of employees in this field. The optimal volume of the module is 7-9 didactic units. The identified occupational risks should be included in each module based on a classification based on the nature of the risk. This presentation of the theory will be relevant to specific occupational risks in the workplace.

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⁴ Ob utverzhdenii Tipovogo polozheniya o sisteme upravleniya okhranoy truda. [On the approval of the Model Regulation on the occupational Health and Safety management System].



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Theoretical study of the model of air flow movement near the shaped shelter of the rough grinding machine

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Introduction. The article deals with the problems of choosing equipment for effective dust removal and subsequent dust collection. The dependences describing the fields of flow velocities in the closed area of the abrasive wheel, influencing the formation of streamlines of flow motion near the shaped shelter of the rough grinding machine, are considered.

Problem Statement. The objective of this research is to develop a mathematical and computer model of the aspiration of a rough grinding machine.

Theoretical Part. To accomplish the set task, the modern software Ansys was used as well as the previously obtained results of the dispersion analysis of abrasive-cast iron dust during grinding, which had been carried out using a High-class device — an Analysette22 NanoTec laser granulometer.

Conclusion. The results of the analysis, the obtained fields and the values of the air flow velocities in the workplace of the machine operator will be compared with the hovering rates of various dust particles, which will allow us to determine the efficiency of the rough grinding machine shelter, including at the design stage.

Keywords: aspiration, Ansys, dust, peeling machine, computer model, mathematical model.

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Introduction. To remove dry dust particles of different dispersion from under the shelters of technological equipment, aspiration with dust-collecting and dust-cleaning equipment is used, the efficiency of which is provided by a preliminary aerodynamic calculation.

Since the capture of dust particles in aspiration systems and dust cleaning devices is characterized by the competition of inertial and aerodynamic forces, the calculation is based on the physical criteria that make up the geometry of the particles with their mass.

To remove dust effectively and then collect it, it is necessary to develop:

- a mathematical model for the dispersion of abrasive-cast-iron dust during rough grinding of brittle parts;
- mathematical and computer models of aspiration of a rough grinding machine;
- to propose an engineering method for calculating the efficiency of the shaped shelter and selecting the elements of the dust removal and dust collection system for grinding machines of the class under consideration.

The mathematical and computer models of aspiration of a rough grinding machine, implemented in the modern software Ansys, are presented below.

The dependences describing the velocity fields of the flow movement in the closed area of the abrasive wheel are obtained, which influence the formation of flow lines near the shaped shelter of the rough grinding machine, which will further determine the efficiency of the shelter of the rough grinding machine, including at the design stage.

Problem Statement. In the process of roughing and grinding, two dust streams (plumes) are formed at the point of contact of the part and the abrasive wheel. The first stream moves tangentially to the circle of the abrasive wheel (straight plume), the other stream is directed along the rotation of the abrasive wheel itself (reverse plume) (Fig. 1). The shape and direction of these dust streams are visible on the firing lines formed during the operation of the grinding machine.

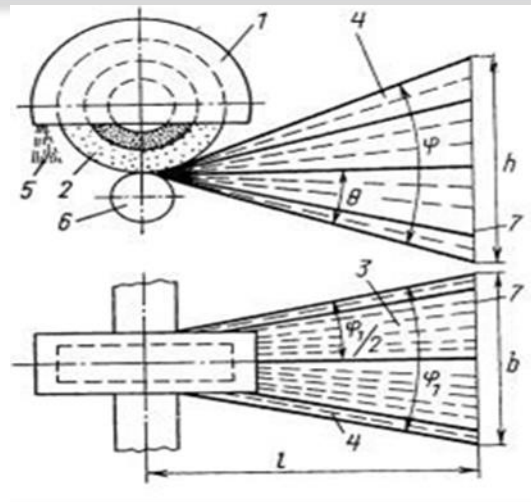


Fig. 1. Dust flows formed during grinding: 1 — cover, 2 — abrasive wheel, 3 — straight plume, 4 — invisible part of the plume, 5 — reverse plume, 6 — work piece, 7 — dust collector

When grinding without cooling the main stream of dust particles is wedge-shaped and directed in the direction of rotation of the abrasive wheel (Fig. 1). The wedge angle φ is the deviation of the main flow from the machined surface of the workpiece; it depends on the cutting parameters and physical and mechanical properties of the processed material [1].

The maximum efficiency of dust collection of abrasive-metal dust during grinding can be achieved if the design features of the dust collector are observed, taking into account the direction of movement of dust particles, as well as the possibility of regulating the design of the dust collector during the abrasive wheel wear. It is important that the dust collector is connected to the protective cover (casing) of the grinding machine. Shelters-dust collectors with storage devices are considered perfect if they require slightly less air for effective dust extraction due to the use of the kinetic energy of the flying chips and dust (Fig. 2) [2–3].

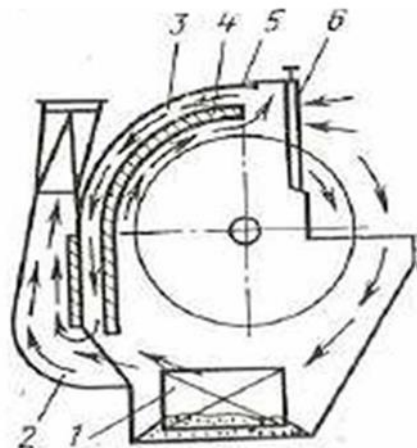


Fig. 2. The scheme of the fence of the dust collector for a grinding machine with a large dust accumulator:

1 — large dust accumulator, 2 — suction pipe, 3 — channel, 4 — partition, 5 — housing,
6 — flap to prevent dust from entering the workplace

The efficiency of dust collection and the safety of the grinding process largely depend on the design parameters of the protective casing-dust collector, including the size of the gap between the circle and the casing.

The protective casing must meet a number of requirements:

- the material for casing manufacture must have the maximum strength to prevent damage to the casing when the abrasive wheel breaks;
- the area of the cover of the abrasive wheel should be maximum, but not obstructing the processing of the part;
- the ability to adjust the position of the casing along the spindle axis, taking into account the wear of the wheel;
- the use of the casing as a dust intake, taking into account the direction of movement of dust flows;
- the possibility of attaching a dust-collecting device to the casing as the first stage of cleaning [2-3].

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i} (\rho u_i) = 0, \quad (1)$$

where x_i — the i -th spatial coordinate, m;

equation of moments (motion):

$$\frac{\partial (\rho u_i)}{\partial t} + \frac{\partial (\rho u_i u_j)}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j} \left(\mu \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \right) + G_i \quad (2)$$

Heat transfer is determined by the equation:

$$\frac{\partial (\rho h)}{\partial t} + \frac{\partial (\rho u_i h)}{\partial x_i} = \frac{\partial}{\partial x_i} \left(\mu \frac{\partial h}{\partial x_i} \right) + Q, \quad (3)$$

where Q — the function of heat sources, W/m³;

energy equation for the calculation of temperature characteristics:

$$\frac{\partial (\rho T)}{\partial t} + \frac{\partial (\rho u_i T)}{\partial x_i} = \frac{\partial}{\partial x_i} \left(c_p \cdot \frac{\partial T}{\partial x_i} \right), \quad (4)$$

where ρ — density, P — pressure, u_i — components of the velocity vector, T — temperature, x_i — coordinates, μ — viscosity, c_p — specific heat capacity, k — thermal conductivity, $G_i = -\rho \cdot g_i$ — gravity component, h — enthalpy.

When using k - ω turbulence models, equations (1)–(2) are converted to form (4), in which the influence of the average velocity fluctuation (in the form of turbulent kinetic energy) and the process of reducing this fluctuation due to viscosity (dissipation) are added.

Two additional equations for the transport of the kinetic energy of turbulence and the equation for the rate of dissipation of the turbulent energy (5)–(6) are also added.

$$\frac{\partial (\rho k)}{\partial t} + \frac{\partial (\rho \bar{u}_i k)}{\partial x_i} = \frac{\partial}{\partial x_j} \left(\left(\mu + \frac{\mu_t}{\sigma_{k1}} \right) \frac{\partial k}{\partial x_j} \right) + P_k - \beta' \cdot \rho \cdot k \cdot \omega, \quad (5)$$

$$\frac{\partial (\rho \omega)}{\partial t} + \frac{\partial (\rho \bar{u}_j \omega)}{\partial x_j} = \frac{\partial}{\partial x_j} \left(\left(\mu + \frac{\mu_t}{\sigma_{k1}} \right) \frac{\partial \omega}{\partial x_j} \right) + \alpha_1 \cdot \frac{\omega}{k} \cdot P_k - \beta_1 \cdot \rho \cdot \omega^2, \quad (6)$$

k -equation:

$$\frac{\partial (\rho k)}{\partial t} + \frac{\partial (\rho u_j k)}{\partial x_j} = P_k - \rho \cdot C_\mu \cdot k \cdot \omega + \frac{\partial}{\partial x_j} \left(\left(\mu + \frac{\mu_t}{\tilde{\sigma}_k} \right) \frac{\partial k}{\partial x_j} \right), \quad (7)$$

ω -equation:

$$\frac{\partial(\rho\omega)}{\partial t} + \frac{\partial(\rho u_j \omega)}{\partial x_j} = \tilde{C}_{\omega 1} \frac{\omega}{k} P_k - \tilde{C}_{\omega 2} \rho \omega^2 + (1-F) \cdot \frac{2 \cdot \rho}{\sigma_\omega \cdot \omega} \cdot \frac{\partial k}{\partial x_j} \cdot \frac{\partial \omega}{\partial x_j} + \frac{\partial}{\partial x_j} \left(\left(\mu + \frac{\mu_t}{\tilde{\sigma}_\omega} \right) \frac{\partial \omega}{\partial x_j} \right), \quad (8)$$

where,

$$\tilde{\varphi} = \varphi_1 \cdot F_1 + \varphi_2 \cdot (1-F_1), \text{ where } \tilde{\varphi} = \tilde{C}_{\omega 1}, \tilde{C}_{\omega 2}, \frac{1}{\tilde{\sigma}_k}, \frac{1}{\tilde{\sigma}_\omega},$$

$$C_{\omega 11} = 0,55; C_{\omega 21} = 0,075; \sigma_{k1} = 2; \sigma_{\omega 1} = 2; C_\mu = 0,09$$

$$C_{\omega 12} = 0,44; C_{\omega 22} = 0,083; \sigma_{k2} = 1; \sigma_{\omega 2} = 1,17$$

μ_t — the coefficient of turbulent dynamic viscosity, k — turbulent kinetic energy (in the case of laminar flows $k=0$).

The boundary conditions for the system of equations (1)–(8) are the following parameters (Table 1).

Table1

Boundary conditions of the boundary value problem

Speed: u_i	(9)
Static exit pressure 0 relative to the external pressure (free boundary). $P=0$. All pressures here and below are set and obtained in the results relative to the external pressure. To obtain the total pressure, add the atmospheric pressure to these values.	(10)
On the inner walls, the adhesion conditions, the velocities are equal to 0.0. $u_i = 0$	(11)

For the energy equation (3)–(4), the boundary conditions are given in two versions. The heat flow on the walls q is determined from the formula:

$$q = h \cdot (T_1 - T_2), \quad (12)$$

where h — heat transfer coefficient, T_1 — temperature on the outer wall, T_2 — temperature on the inner wall.

The temperature on the outer wall T_1 and the heat transfer coefficient h . Further, the boundary value problem (3)–(12) can be solved numerically [4–13].

The equation of state for an ideal gas corresponds to the Mendeleev-Clapeyron law, the variable density can be calculated from the formula:

$$\rho = \frac{P \cdot M}{R \cdot T}, \quad (13)$$

where ρ — air density, P — pressure, R — gas constant, J/(mol·K), T — temperature, M — molecular weight of the air (28.966 g/mol).

The dependence of the viscosity coefficient on the thermodynamic values is established using the kinetic theory. In the calculations, the Sutherland formula is used to determine the dynamic viscosity coefficient:

$$\mu = \left(\frac{T}{273,15} \right)^{\frac{2}{3}} \cdot \frac{273,15 + C_S}{T + C_S} \cdot \mu_0, \quad (14)$$

where C_s — Sutherland constant, μ_0 — the dynamic viscosity coefficient under normal conditions, kg/m s.

The initial conditions for the system of equations (1)–(8) are: the mass flow rate of air G kg/s at the outlet of the casing, which is removed from the rough grinding machine by the fan. In this case, the amount of air removed is determined depending on the diameter of the grinding wheel d_{kp} according to the formula, m³/h:

$$L_1 = 1,8 \cdot d_{kp}. \quad (15)$$

Formula (15) is valid for $250 \text{ mm} < d_{kp} < 600 \text{ mm}$. The air velocity is determined from the formula:

$$u_i = \frac{G}{\rho \cdot S}, \quad (16)$$

where ρ — density, S — the area of the passage section.

The calculated speed of air intake in the intake opening of the casing is, m/s: $v_0 = 0,25 \cdot v_{okp}$ — from the circumferential speed when the plume is directed into the intake opening of the suction duct; $v_0 = (0,3 \dots 0,4) \cdot v_{okp}$ — when the dust plume is directed parallel to the suction opening of the connected air duct.

The circumferential speed of the grinding wheel is determined by the formula:

$$v_{kp} = \frac{\pi \cdot d_{kp} \cdot n}{60 \cdot 1000}, \quad (17)$$

where n — the speed of rotation of the grinding wheel, taken from the technical characteristics of the machine.

Figures 3a, b show the geometry and design scheme of the studied shaped shelter of the rough grinding machine.

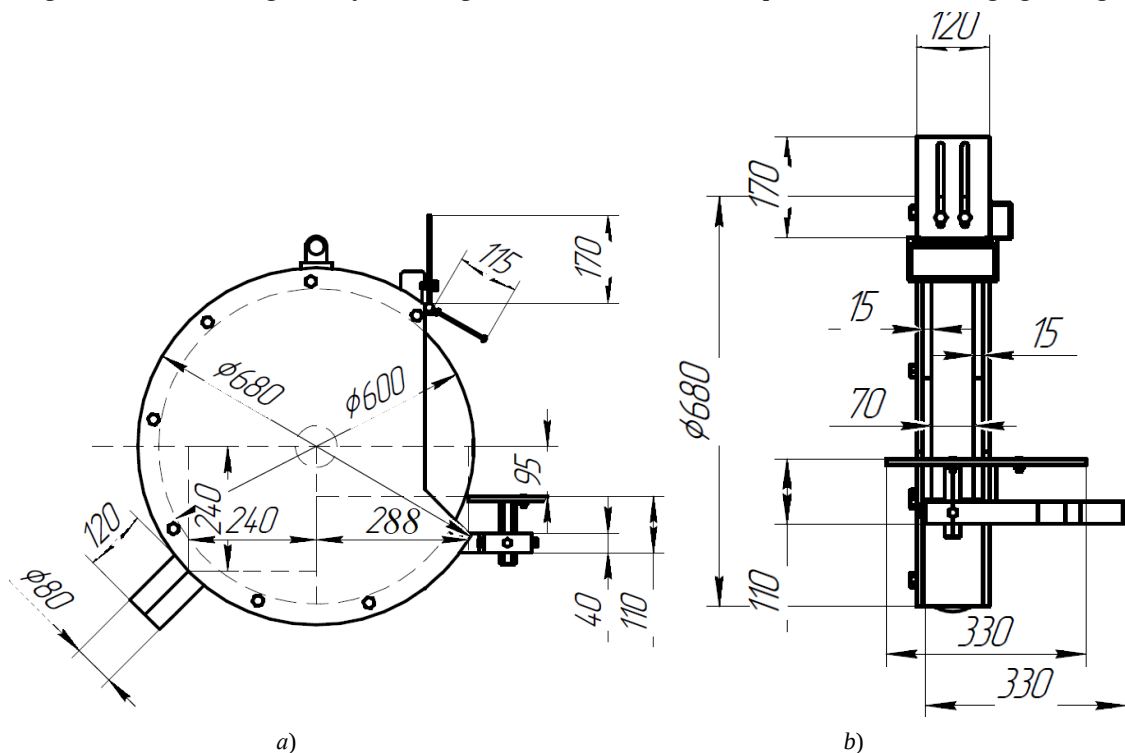


Fig. 3. Basic design scheme: a — side view, b — end view

Problem Statement. Computer model of a rough grinding machine aspiration.

A 3D model of the area was created, starting from the air inlet (the point of contact of the wheel with the part — the formation of abrasive) to the middle of the grinding wheel. The 3D model simulates an internal air domain bounded by a circle, a casing, and free surfaces (air inlets and outlets) (Fig. 4a, b).

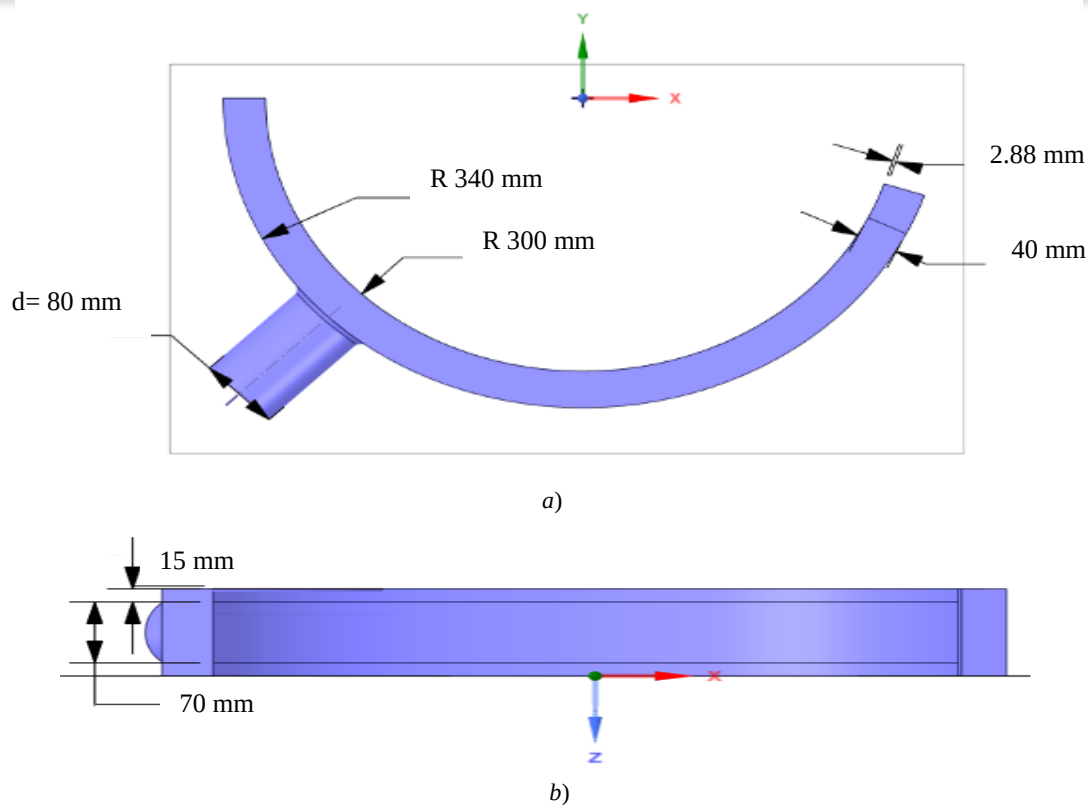


Fig. 4. Computational domain: a — side view, b — top view

The gap between the outer surface of the grinding wheel and the inner surface of the protective casing is assumed to be 40 mm in the first approximation.

This design parameter of the machine can be changed. A 5 mm chamfer has been added to the inlet.

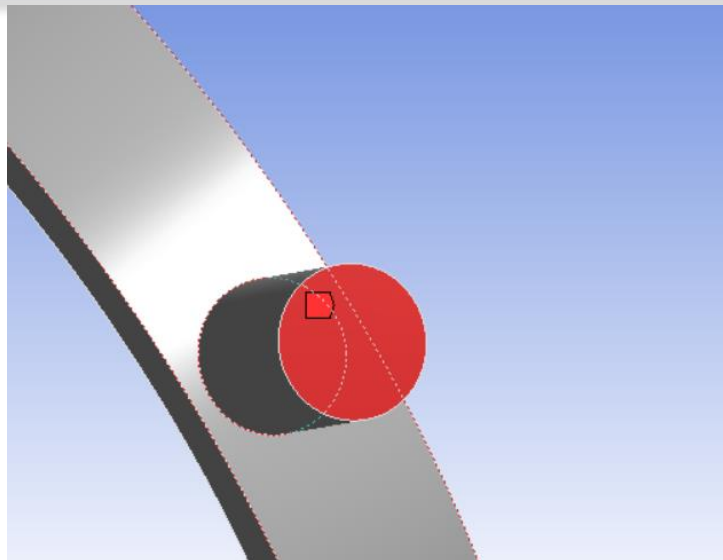
Boundary conditions:

1. Wall, sticking conditions (zero speeds). On this surface, the air moves at the speed of rotation of the wheel (Table 2).
2. The inlet of the air flow at a speed of 30.77 m/s.
3. Suction, air flow rate of 1080 m³/h (Fig. 5 a).
4. Free surfaces with zero pressure relative to the external atmospheric pressure. Air can enter and exit through these surfaces, depending on the task parameters. The gap between the grinding wheel and the casing is also a free surface that can be changed (Fig. 5 b).

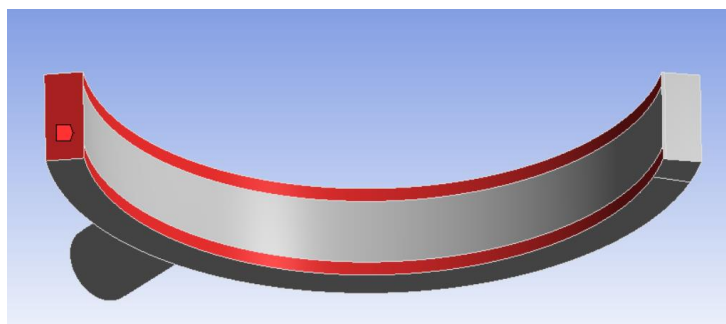
Table 2

Calculated parameters

Name	Value	Unit of measurement
Air density	1,225	kg/m ³
Air viscosity	$1,7894 \cdot 10^{-5}$	kg/m·s
Wheel speed	980	rpm



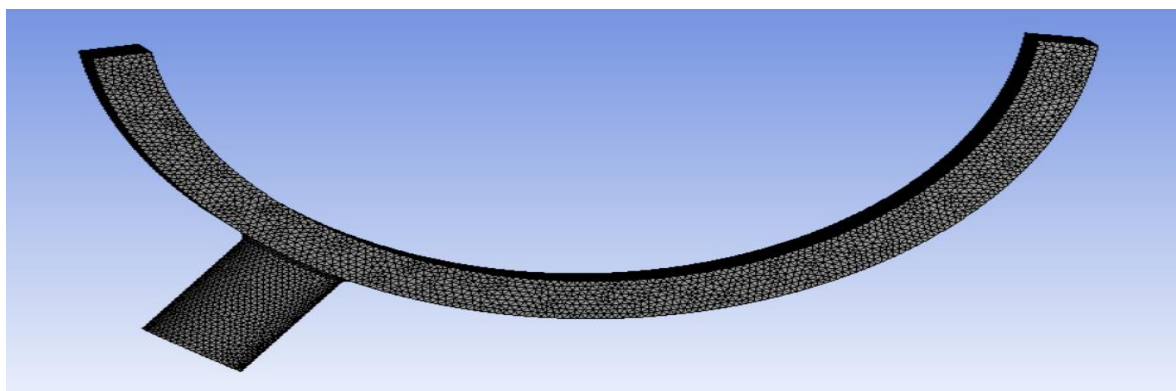
a)



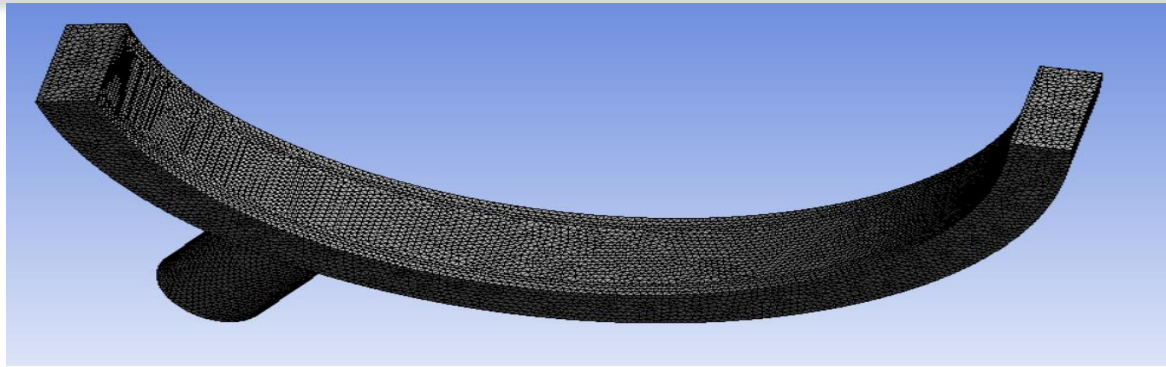
b)

Fig. 5. Boundary conditions in the model: a — suction from the machine, air flow of $1080 \text{ m}^3/\text{h}$, b — free surfaces with zero pressure

Calculated grid of finite volumes. Model calculations of the processes were carried out with different grid structures. The size of the calculated grid in the middle zones of the channels is 25 mm. Above the outer borders and in the transition area from the casing to the suction pipe, thickening in the form of wall layers is performed (Fig. 6a, b).



a)



b)

Fig. 6. Grid of finite volumes: a — side view, b — top view

In the 3D model, the corresponding boundaries that are responsible for the boundary conditions of the model are highlighted in red (Fig. 5, 7).

The section in Fig. 7 models the support for the parts. For convenience, the support surface is located along the radius. The surface of the stand in the boundary conditions is the boundary conditions of the wall, the area between the table and the wheel is the air inlet at the appropriate speed, and the part not covered by the casing is the free surface for the air inlet and outlet (marked in green).

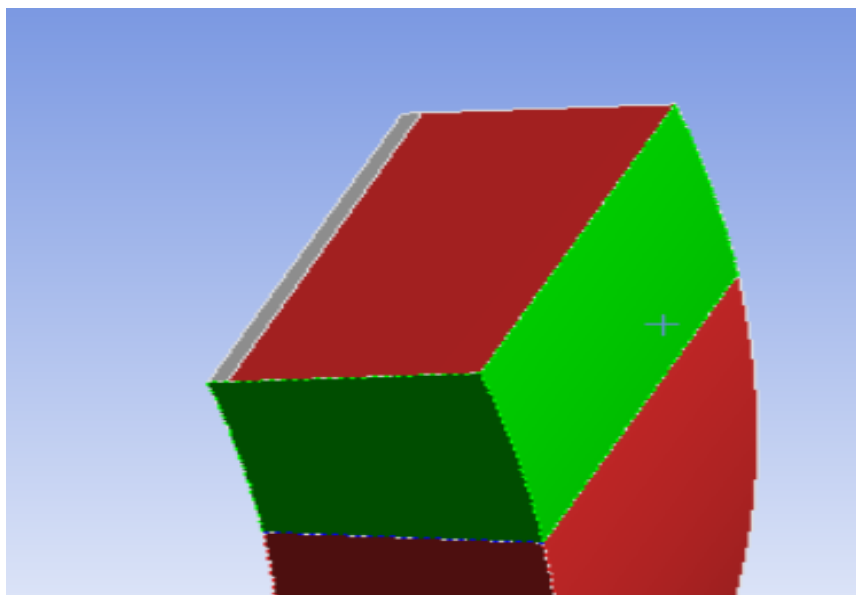


Fig. 7. Model of the support

Results of model calculations of shelter aerodynamics. Figure 8 shows the flow velocity field formed during the operation of the hood of the rough grinding machine. As you can see from the calculation results, the field is extremely uneven. The speeds vary from a maximum of 60-80 m/s at the inlet of the flows into the suction pipe of the machine to a minimum in the space of the channel between the grinding wheel and the casing [14]. For a more detailed understanding of the flow velocity distribution pattern, we will construct the current velocity lines (Fig. 9–12).

Figure 9 shows the results of the modeling of the flow motion in the space between the abrasive wheel and the casing, as well as in the cylindrical branch pipe of the suction hood.

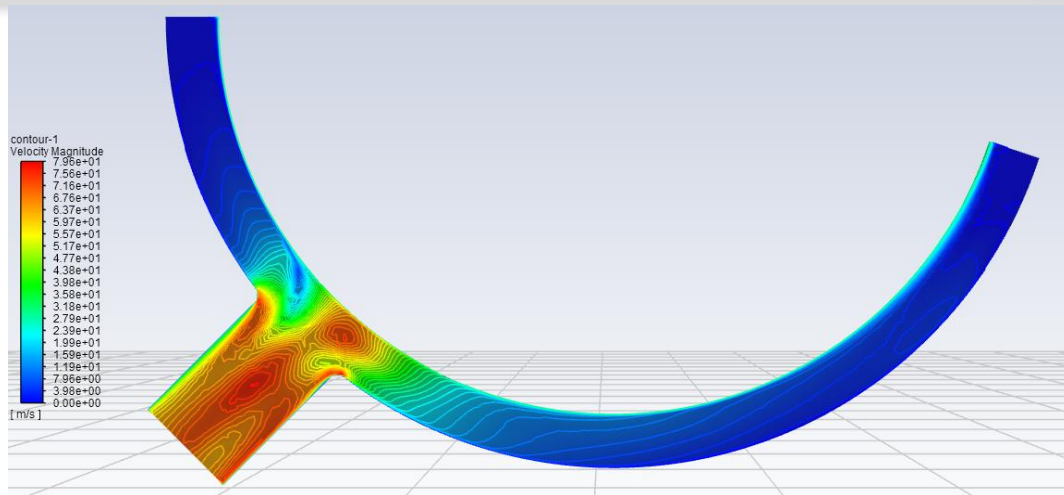


Fig. 8. Flow velocity field in the channel

Figure 9 shows the velocity current lines — the trajectories of particle motion. The color is responsible for the trajectories numbers. It can be seen that the input velocity of the air flow into the closed part of the machine casing corresponds to the values of 30-34 m/s. At a distance from the exhaust pipe, on the contrary, a reverse air flow with low speeds is formed.

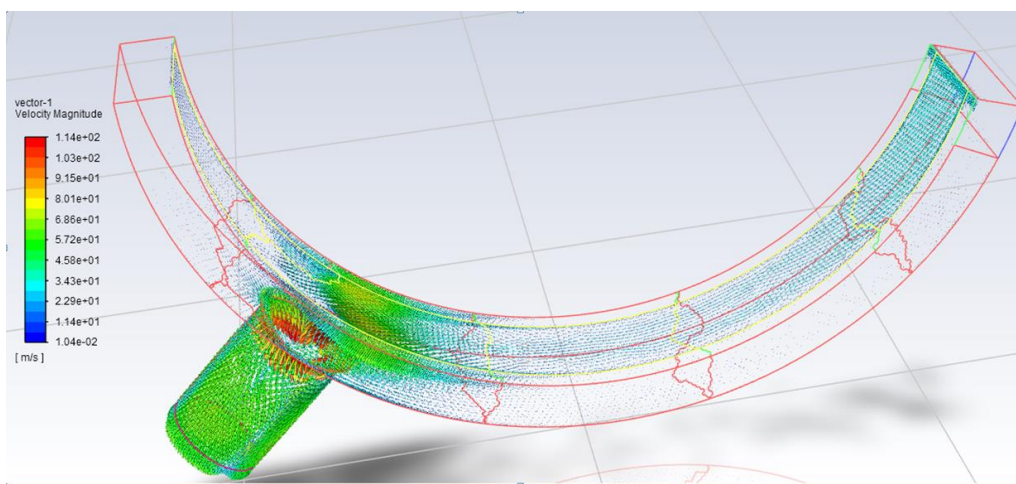


Fig. 9. Image of flow velocity vectors

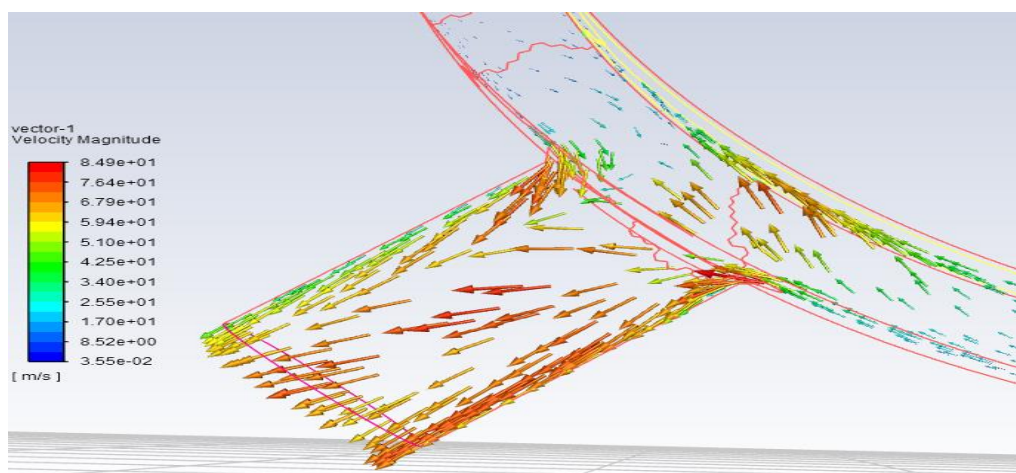


Fig. 10. Numerical values of flow velocity vectors

Velocity current lines are the trajectories of the expected dust particles. The color is responsible for the trajectories numbering.

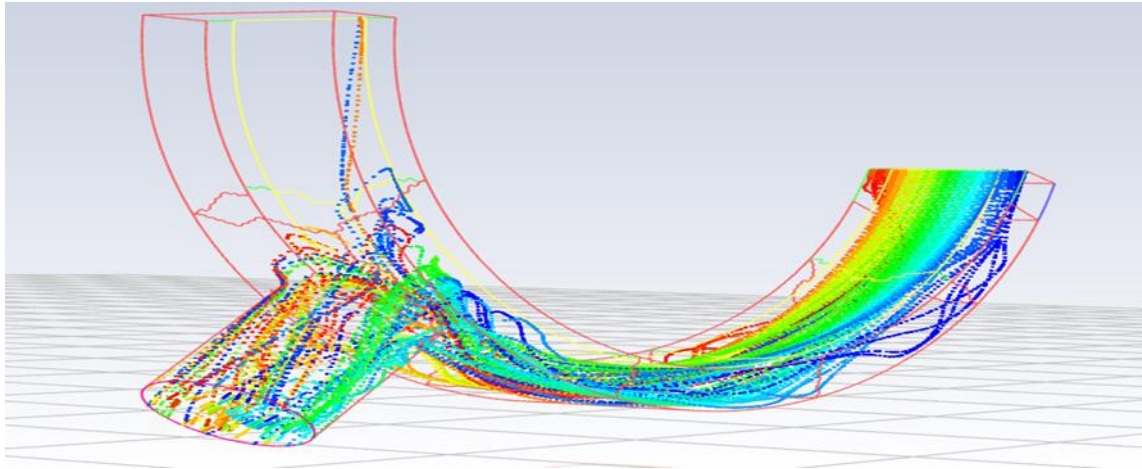


Fig. 11. Image of current velocity lines

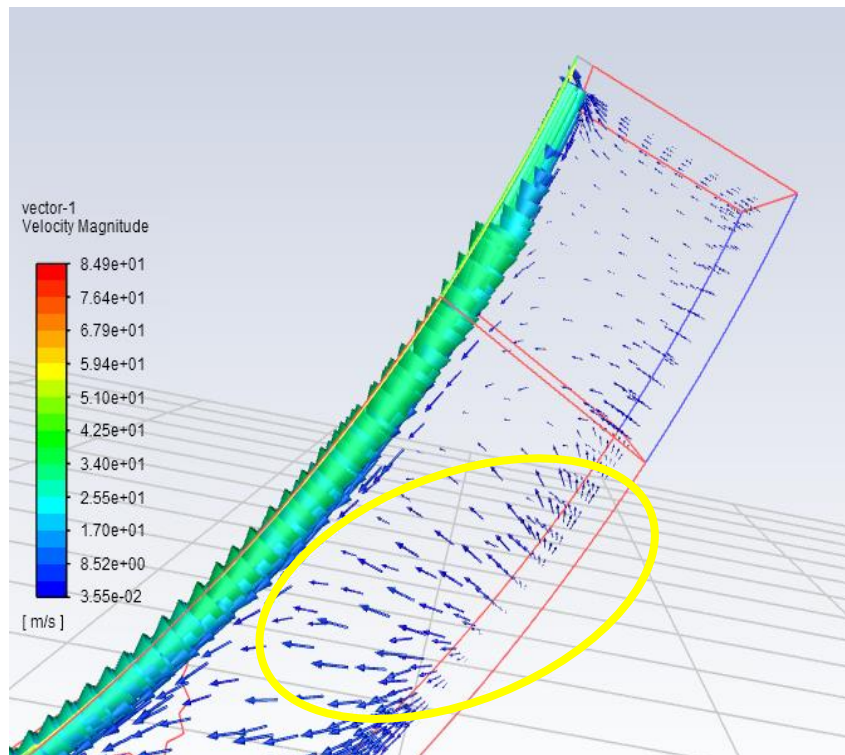


Fig. 12. Image of the vortices of the air flow at the entrance to the casing

The yellow outline shows the swirls at the beginning of the casing, where the flow divides in different directions from the casing wall.

According to the results of the CFD calculation, the average particle velocity at the suction site is about 60 m/s, but a more complex distribution pattern of the velocity gradient with local values up to 80 m/s is observed.

Figure 13 shows the flow velocity vectors at the outlet of the casing with the circular shape of the exhaust pipe.

It should be noted that in the immediate vicinity of the abrasive wheel, a reverse plume is formed, as in Figure 1, which leads to the release of dust particles to the operator's workplace. The speed of this flow is from 0.355 to 1.7 m/s (Fig. 13).

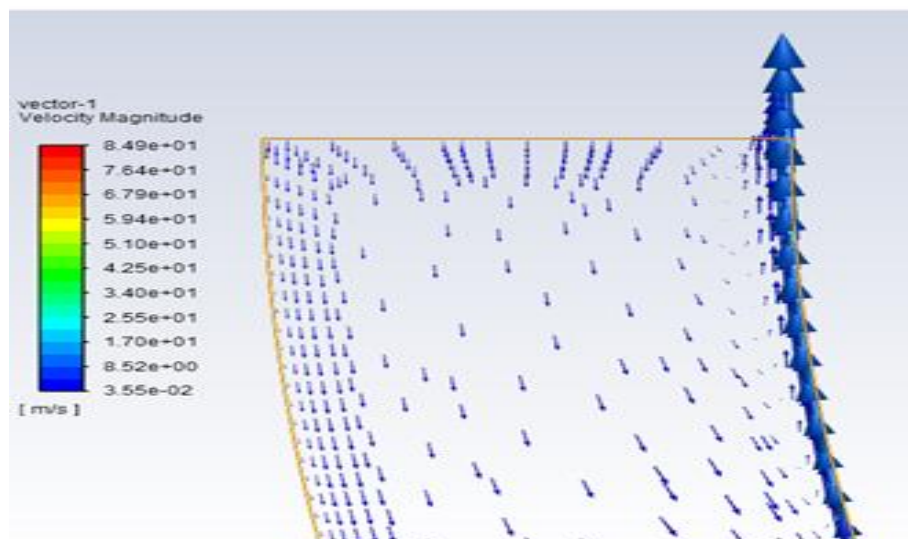


Fig. 13. Values of the velocity vectors of forward and reverse flows at the exit from the shelter

Conclusion. The developed computer model made it possible to determine the directional fields and the values of the air flow velocities in the closed area of the abrasive wheel and in the exhaust cylindrical pipe going to the fan.

However, to ascertain a more complete picture of dustiness of a grinder workplace you need to find out what are the field lines of the current flows and the values of velocity near the shaped shelter of the rough grinding machine, i.e. in the space where the circle is not closed by the shaped shelter.

The obtained fields and the values of the air flow velocities at the shaped shelter of the grinding machine (in the open part of the abrasive wheel), i.e. at the point where dust enters the air of the working area, will be further compared with the hovering velocities of various dust particles, which will ultimately determine the efficiency of their capture.

Conclusions:

1. Mathematical and computer models of aspiration of a rough grinding machine are developed, implemented in the modern software Apsus.
2. The computer model allows you to determine the rational (minimum necessary) amount of air removed and the effect of abrasive wear of the grinding wheel on the aerodynamic characteristics of the shelter of the grinding machine.
3. The dependences are obtained describing the velocity fields of the flow in a closed region of the abrasive wheel, influencing the formation of lines of current flow near the shaped shelter of the rough grinding machine, which in the future will allow us to determine the shelter effectiveness of the rough grinding machine, including at the design stage.

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Determination of capacity and comfort indicators of a passenger elevator

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Introduction. Elevators are mass weight-handling units used by millions of residents of multi-storey buildings. Safety of elevator units and comfort of their use are determined not only by the correct choice of their design and parameters, but first of all, by the organization of the maintenance system. Each elevator is an individual unit that serves a residential building with a specific number of passengers, number of floors and other features. However, regulatory documents recommend standard maintenance plans. There is the need to establish the relationship between the loading modes of the main components and the optimal scheme of technical and repair works. The present work is devoted to the solution of this problem, along with the study of transport comfort.

Problem Statement. The operation of the elevator in a residential building with a number of floors N occurs in separate cycles. Standing, lift call, and destination floors are random variables for which probabilistic characteristics must be reliably established. In general, the elevator operation mode includes three stages: calling to the passenger boarding level, moving with passengers to the destination level, and waiting for the next cycle. There are stops inside the movement stages.

The specific problem of mathematical description of the random process of implementing the operating characteristics of the main drive of the elevator is reduced to two directions: 1) the development of mathematical models for the formation of the main indicators of the main elevator drive load during the cycle (net machine time τ_{mi} and the number of switches n); 2) the study of the relationship between passenger traffic, building residential density and cycle duration.

Theoretical Part. To meet these objectives the authors have performed the studies of the following main processes characterizing the functioning of the lift, the level of capacity of the transport drive and comfort: the development of mathematical models of formation of indicators of the elevator drive load; the establishment of the relationship of traffic flow, residential density and the duration of the cycle; development of methodology for calculation of the number of flights went by the elevator in different modes; development of methods of calculating the transport comfort indicator; justification of the structure of the algorithm for modeling the operating modes of the elevator.

Conclusion. The paper provides the results, which complement the theoretical provisions for determining the capacity and transport comfort of elevators.

Keywords: passenger elevator, load level, transport comfort, operating mode, machine time coefficient, specific number of switches, mathematical models of elevator operation, simulation algorithm.

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Introduction. According to the definition formulated in the regulatory standard, "an elevator is an intermittent action lifting machine designed for lifting and lowering people and (or) cargo in a cabin moving along rigid rectilinear guides, which have an angle of inclination to the vertical of no more than 15° " [1]. Most high-rise buildings around the world are equipped with these devices. To date, about 500 thousand elevator units are in operation in Russia. The scale of design, manufacture and application of elevators will increase due to the growth of multi-storey construction of residential and public buildings.

The requirements for elevator units are defined by the main document — the Technical Regulations of the Customs Union [2]. Among them, the most important requirements are the safety and comfort of passengers. Obviously, each of these requirements can be represented in the form of multi-factor dependencies that must be taken into account when designing, manufacturing and operating elevator units.

Safety in the operation of an elevator unit mainly depends on two groups of factors:

- the load level of the load-bearing elements and its compliance with the regulatory values;
- ensuring the necessary quality of maintenance.

It is obvious that the scope and content of maintenance procedures should be related to the actual loads acting on the power elements of the unit, primarily the main drive, including the rope-traction mechanism, the door drive, and a number of others.

The loads of the main drive subsystem — engine, transmission, rope-traction mechanism — are formed in accordance with the operating mode. For the cyclic mode of operation of an elevator unit, it is important to distinguish two main kinematic indicators: the relative operating time of the drive and the number of switches on (decelerations) per the unit of time. Each of these indicators indirectly characterizes the operating torques and forces in the critical nodes. The establishment of these indicators does not exclude the need to determine the actual loads. The work of Khazanovich G. S., Otrokov A. V., Aprishrin D. S. Computer Modeling of Dynamic Processes of Passenger Elevators at Casual External Influence is devoted to these issues [3]. At the same time, the information on the regime kinematic indicators will allow you to pre-evaluate the degree of power load of the elevator unit without complex calculations.

The indicator "transport comfort" is defined by GOST R 52941-2008 (ISO 4190-6: 1984). National Standard of the Russian Federation. Passenger elevators [1]. It represents the interval of movement of elevators, expressed as the period of time between two consecutive departures of elevator cabins in a given direction on the main landing floor. At the same time, the main landing floor is the floor where people entering the building have access to the elevators.

The authors emphasize that the indicator of transport comfort is a random variable — it is the time interval between two consecutive cycles when the elevator moves up from the first floor to the destination floor. The comfort indicator, of course, in real conditions varies from the minimum to the maximum value. The most representative value of the comfort indicator can be the average value in different periods of daily operation: morning, afternoon, evening and night.

The cycle consists of the following elements: calling, elevator moving from the waiting floor to the first floor, a random number of passengers landing on the first floor, moving up to the destination floor with random stops. To calculate the average load and transport comfort of the elevator, the following initial data are required:

- number of floors of the building — N ;
- distance between floors — h , m;
- the average speed of the elevator car — v , m/s;
- elevator load capacity as the maximum number of passengers — R ;
- statistical series of the distribution of the number of passengers — r entering the elevator for the next i -th flight;
- distribution series of the number of the elevator standing floor number — L when calling it from the first floor or intermediate floors;
- distribution series of the number of intermediate stops — R_n when the elevator moves from the first floor to the final destination floor — S ;
- distribution series of the number of elevator stops when moving up with passengers — n ;
- distribution function of the cycle duration — τ or the waiting time for the next cycle — Δ .

The justification of the list of other source data is given in the process of presenting the material of the article.

It is obvious that the indicator of transport comfort, as well as the characteristics of the elevator load, can be obtained only on the basis of simulation of the operating mode of the unit as a random process. These tasks can and should be solved together based on the unified mathematical models for the formation of kinematic characteristics of an elevator unit.

Research Rationale. The relevance of this study arises from the need to assess the level of load of the main power units of the elevator unit and transport comfort in advance, at the stage of designing the elevator or choosing a standard size from among the proposed options. This will allow you to determine in advance the type and characteristics of the engine, the speed of the cabin and other indicators.

The aim of the work is to develop a mathematical apparatus for providing the process of simulation of kinematic modes of operation of passenger elevators, which allows you to set the indicators of congestion and transport comfort of passenger elevator units.

Problem Statement. The elevator operates in a residential building with a number of floors N in separate cycles. The number of an arbitrary cycle is denoted by i , $1 \leq i \leq I$, where I is the total number of cycles for a certain observation period. Each cycle consists of three periods:

- 1) a call in which the elevator moves without passengers from the standing level after the previous cycle on the floor L to the passengers waiting level on the floor M ;
- 2) movement of the elevator with passengers from the floor M to the destination floor S ;
- 3) a pause of Δ duration, s (Fig. 1).

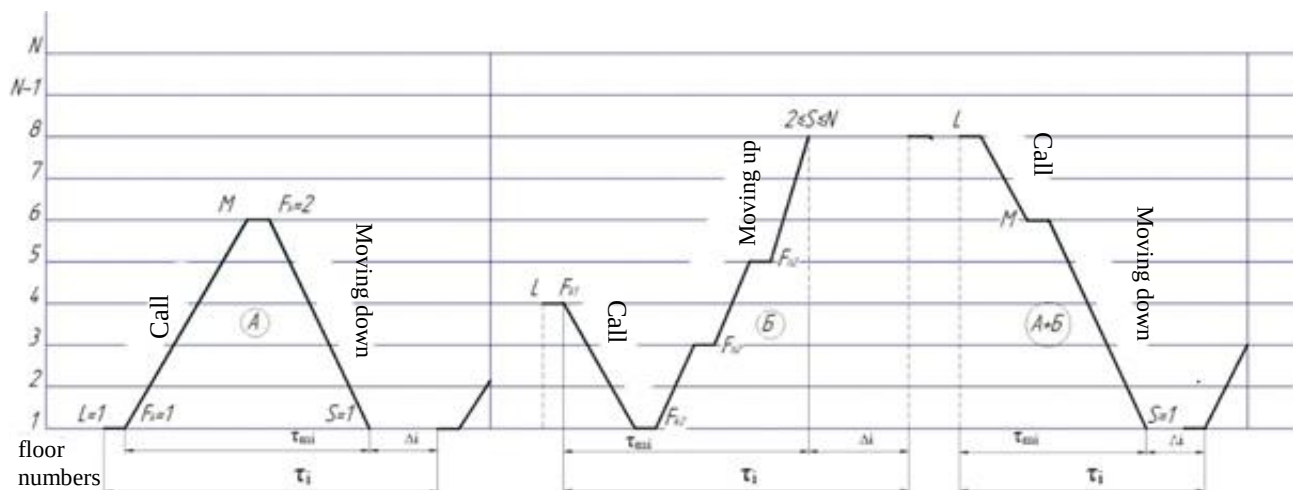


Fig. 1. Kinematic structure of the cycles: A — call and movement to the first floor without intermediate stops; B — call and movement from the first floor to an arbitrary floor S with intermediate stops; A+B — call from an arbitrary floor L to an arbitrary floor M and movement to the first floor without intermediate stops (vertical — floor numbers, horizontal — conditional time in minutes)

The values L , M , and S are random integer variables that take values in the ranges:

- when the elevator is supposed to move down to the first floor (cycle A) — $1 \leq L \leq N$; $2 \leq M \leq N$; $S=1$;
- when the elevator is supposed to move up from the first floor (cycle B) $M=1$ to the destination floor S , $2 \leq L \leq N$; $2 \leq S \leq N$.

Within each of the 1 and 2 periods, there are intermediate R_{ni} and final R_{ki} stops, at each of which the main drive is activated (decelerated), the number of which in each cycle is equal to n_i , as well as doors open and close with passenger entry and exit.

After the end of the 1 and 2 periods, there is a random pause time Δ_i before the start of the next cycle. The value of Δ_i is a continuous random variable that depends primarily on the actual passenger traffic. The total duration of an arbitrary cycle is indicated by τ_i , and the duration of the drive operation, measured in net machine time in minutes (NMT), is indicated by τ_{mi} .

Thus, the specific task of the mathematical description of the random process of implementing the operating characteristics of the main drive of the elevator is reduced to two directions:

- 1) development of mathematical models for the formation during the cycle of the main indicators of the load of the main elevator drive: net machine time τ_{mi} and the number of switches n_i , including:

- when the elevator moves down (cycle type A);
- when the elevator moves up (cycle type B);
- with stochastic alternation of directions of movement (cycle type A+B);

- 2) study of the relationship between the passenger traffic, residential building density and cycle duration.

Theoretical Part. Mathematical models of the formation of elevator drive capacity indicators. Let us denote the random distance went by the elevator cab in the i -th cycle, K_{npi} . If the interstorey distance (in meters) is $h = \text{const}$, and the average speed, taking into account acceleration and deceleration — is v m/s, then the average net machine time (NMT) per cycle in the interval $1 \leq i \leq I$ will be:

$$\tau_{mcp} = \frac{h}{60v} \cdot \frac{\sum_{i=1}^I K_{npi}}{I}, \quad (1)$$

and the average number of switches on of the main drive per NMT minute:

$$n_{cp} = \frac{\sum_{i=1}^I n_i}{I} \cdot \frac{1}{\tau_{mcp}} = \frac{\sum_{i=1}^I n_i}{\sum_{i=1}^I K_{npi}} \cdot \frac{60v}{h} \quad (2)$$

The above relations allow us to draw preliminary conclusions:

— the average value of the net machine time of the cycle τ_{mcp} depends proportionally on the accumulated number of spans passed by the cabin $\sum_{i=1}^I K_{npi}$ and inversely proportional to the average speed of the cab;

— the average specific number of n_{cp} switches on is proportional to the average speed of the elevator v per cycle, with an increase in speed v , the average number of switches on per minute of the NMT increases proportionally.

After analyzing the formulas, we came to the conclusion that in order to develop adequate statistical models of the kinematic characteristics of the operating modes of the elevator drive, it is necessary to specify the order of the elevator movements in different directions and to determine statistical approaches to calculating the total or average values of the number of switches on and the number of spans went by the cabin. For this purpose, as shown earlier, three cases are distinguished: the movement of the elevator down from an arbitrary floor to the first floor without intermediate stops (cycle A), the movement of the elevator up with a random number of intermediate stops (cycle B), and the combined version with a different combination of cycles A and B.

Let us consider cycle A as the initial one, which is typical for the morning time: the movement of passengers is from an arbitrary floor M down to the first floor $S=1$ without intermediate stops.

Each cycle starts with the elevator standing on the first floor, $L=1$. The floor of the call is arbitrary in the range from $M=2$ to $M=N$. In this case, the elevator operation cycle has two stages:

1) the movement of the elevator on call from floor $L=1$ to an arbitrary floor $2 \leq M \leq N$. Since the random variable M is distributed a priori according to the law of uniform density, the average number of spans that the elevator passes in the first stage is equal to $K_{np1} = 1/2 \cdot (N+2)$;

2) the movement of the elevator from floor M to the first floor; it is obvious that, by analogy with stage 1, the average number of spans passed by the elevator during the down trip is determined by the same expression- $K_{np2} = 1/2 \cdot (N+2)$.

Then the total average number of spans per cycle is

$$K_{np} = K_{np1} + K_{np2} = N+2. \quad (3)$$

Using the formula (2) to calculate the n_{cp} , we get the total number of switches on for I cycles. It is obvious that each considered cycle has exactly two switches on: the first — at the beginning of the movement of the elevator from standing floor $L=1$ to call floor M , the second — at the beginning of the movement from call floor M to the first floor. Then the total number of switches on for I cycles will be

$$\sum_{i=1}^I n_i = 2 \cdot I.$$

The total number of spans passed by the elevator in I cycles is equal to the sum of random values from $K_{np,i} = 1$ to $K_{np,i} = N-1$, and the probabilities of these values are the same and equal to $P_i = 1/I$. The average value of the number of spans passed by the elevator, as shown above, is equal to $K_{np} = N+2$, and the total number of spans is $\sum_{i=1}^I K_{np,i} = I(N+2)$. Then

$$n_{cp} = \frac{2I}{I(N+2)} \cdot \frac{60v}{h} = \frac{120v}{(N+2) \cdot h}. \quad (4)$$

As it can be seen in the formula (4), the average number of the main drive switches on per minute of its net operating time in the morning mode is proportional to the speed of the cab and inversely proportional to the number of floors of the building.

The average NMT for the period of one random cycle will be

$$\tau_{mcp} = \frac{h(N+2)}{60v}. \quad (5)$$

Figure 2 shows graphs of τ_{mcp} (min. NMT) and n_{cp} (1/ min. NMT) as a function of speed v and the number of floors of building N .

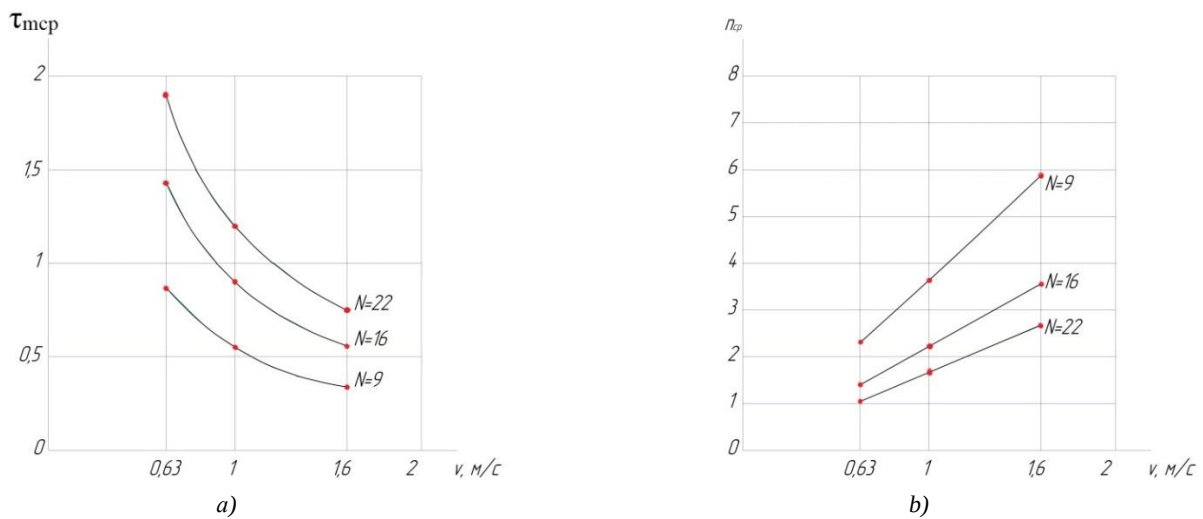


Fig. 2. Dependences for cycles of type A — τ_{mcp} (min. NMT) (a) and the specific number of switches on n_{cp} (1/min. NMT) (b) on the speed of the cab v and the number of floors of building N

Let us consider the features of mathematical models for cycle B (Fig. 1). The cycle consists of the operation of calling the elevator to an arbitrary floor M from the first floor and moving with passengers on the segment M , $S=1$. It is obvious that the average number of spans is determined similarly to the cycle (A), formulas (4) and (5) are valid.

Calculation of the number of spans passed by the elevator in the so-called mixed mode A+B. Mixed mode in a residential building with a number of floors N is the case, in which the elevator is moving down to the first floor ($S=1$) from the call floor M , provided that before the call the elevator was on the standing (waiting) floor L (Fig. 1). In this case, the cases $L>M$ and $L<M$ are possible. It is necessary to find a mathematical expression for calculating the average number of spans passed by the elevator when moving from floor L to floor M . Let us denote this value $K_{np,A+B}$. Obviously, the number of spans in the i -th cycle is equal to $K_{np,(A+B)i} = |M_i - L_i|$. It should be noted that to calculate the average value of a random variable $K_{np,(A+B)}$, it is necessary to consider the numbers M and L as a system of random variables. Each value M , which can take integer values $2 \leq M \leq N$, corresponds to a series of values of the value L from the range $1 \leq L \leq N$. Since a random variable M can take the number of values $N-1$, and L — the number of values N , the total number of combinations (M, L) will be $W_N = N(N-1)$. For example, for buildings with the number of floors $N=9$ — $W_N=72$, for $N=16$ — $W_N=240$, for $N=22$ — $W_N=462$.

Let us note that for a fixed value M_i , the chain $|M_i - L_i|$ consists of two sections. The first section is a decreasing series of natural numbers: $M-1; M-2; \dots; M=L$. The second section is an increasing series of natural numbers: $M-(L+1); M-(L+2); \dots; M-N$. For example, for $N=7$ and $M=3$, the results correspond to the data shown in Table 1.

Table 1

Change in the number of spans $|M-L|$ from the standing level L for $M=3$ (example)

M	3	3	3	3	3	3	3
L	1	2	3	4	5	6	7
$ M_i - L_i $	2	1	0	1	2	3	4
Series	Decreasing			Increasing			

As you can see, both series are arithmetic progressions with the same denominator equal to one. The sum of the terms of an arithmetic progression is determined by the formula $S_n = n(a_1 + a_n)/2$, where n is the number of terms, a_1, a_n

are the values of the first and last terms of the progression [4]. Then the sums of the terms for the decreasing series $\Sigma_I = M(M-1)/2$, for the increasing series $\Sigma_{II} = (N-M)$

$$[1+(N-M)]/2 = [(N-M)+(N-M)^2]/2.$$

For example, for $N=7$ and $M=3$: $\Sigma_I = M \cdot (M-1)/2 = 3 \cdot 2/2 = 3$; $\Sigma_{II} = [(N-M)+(N-M)^2]/2 = [(7-3)+(7-3)^2]/2 = 10$, which corresponds to the data in the table.

Thus, the sum of the terms of the two sections for a specific fixed value of M is determined by the formula:

$$K_{np1u} = \Sigma_I + \Sigma_{II} = \frac{1}{2} [M(M-1) + (N-M) + (N-M)^2]$$

After simple transformations, we get:

$$K_{np1u} = M^2 + \frac{N(N+1)}{2} - (N+1) \cdot M. \quad (6)$$

In total, the number of such chains when M changes from 2 to N will be $N-1$ pieces. Then the total number of spans that can be implemented in each particular cycle is determined by summing when M changes from 2 to N :

$$K_{np\Sigma} = \sum_{M=2}^N M^2 - \sum_{M=2}^N M - \sum_{M=2}^N M \cdot N + \sum_{M=2}^N \frac{1}{2} (N^2 + N).$$

When calculating partial sums, we use Fermat's formula for the first term [4]:

$$\sum_{M=2}^N M^2 = \frac{N(N+1)(2N+1)}{6} - 1. \quad (7)$$

Formula (7) is presented for the case when the sum of squares starts from $M=2$.

The sums in which M is included in the first degree are arithmetic progressions, the method of calculating of which is shown above.

The last term is calculated by the formula:

$$\sum_{M=2}^N \frac{1}{2} (N^2 + N) = \frac{N(N+1)}{2} \cdot (N-1),$$

where the factor $(N-1)$ indicates the number of addition operations when M changes from 2 to N . As a result, the sum takes the form:

$$K_{np\Sigma} = \frac{N}{2} (N^2 - 1) + \frac{N(N+1)(2N+1)}{6} - 1 + (N^2 - 1) \frac{2+N}{2}.$$

Giving such terms, we get a formula for calculating the possible total number of options for spans passed by the elevator in the cycle (A+B):

$$K_{np\Sigma} = \frac{1}{6} N(N+1)(2N+1) - N^2. \quad (8)$$

Expression (8) is a variation of Fermat's formula for the considered case of summing the number of spans [5]. To perform calculations, expression (8) can also be written as:

$$K_{np\Sigma} = \sum_{M=1}^{N-1} M^2. \quad (9)$$

The average number of spans passed by the elevator cab in one cycle during the period of movement from standing floor L to call floor M :

$$K_{np(L-M)} = \frac{K_{np\Sigma}}{W_N} = \frac{N(N+1)(2N+1)}{6N(N-1)} - \frac{N^2}{N(N-1)} = \frac{(N+1)(2N+1)-6N}{6(N-1)} \quad (10)$$

When the elevator moves from call floor M to the first floor, the average number of spans, as shown earlier, will be $K_{np(M-1)} = 1/2 \cdot (N+2)$. Then the general expression for calculating the average number of spans passed by the elevator in (A+B) cycle will take the form:

$$K_{np(A+B)cp} = \frac{(N+1)(2N+1)-6N}{6(N-1)} + \frac{N+2}{2}. \quad (11)$$

Formulas (3), (10) and (11) are universal relations for calculating the average number of spans passed by the elevator in cycles of various types. The constructed graphs give an idea of the dependencies of the components of K_{np} in the function of the number of floors N (Fig. 3).

According to the known value $K_{np(A+B)cp}$, it is possible to determine the net machine cycle time τ_{mcp} and the specific number of switches on n_{cp} using formulas (1), (5). This requires individual indicators of the elevator and the residential building — the average speed of movement v and the interstorey height h .

Mathematical relations (3), (4) and (11) allow us to obtain the component of the average cycle duration in individual periods of elevator operation, which is necessary for simulation modeling

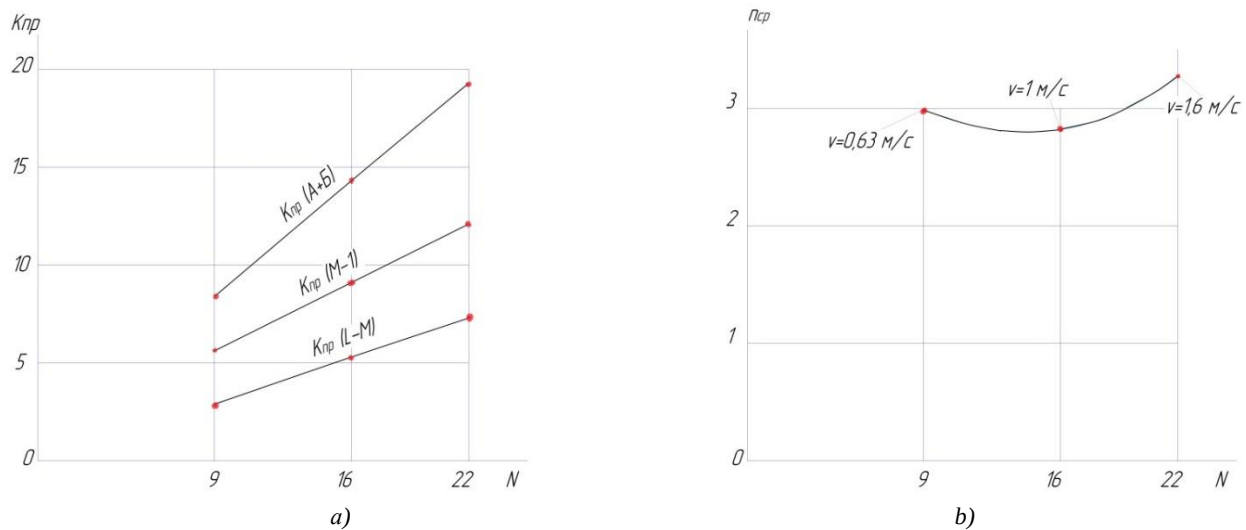


Fig. 3. The dependencies of the average number of spans passed by the elevator, and the specific number of switches on in the cycles of the A+B type on the number of floors of the building and the speed of the cab: a — the number of spans by components when calling (L–M), movement (M–1), and the total; b — the number of switches on per minute in the NMT at cab speeds corresponding to the number of floors of the building

Relationship between passenger traffic, residential building density, and cycle duration. The duration of the elevator cycle τ_i is one of the most important indicators that determine the workload and transport comfort of the unit.

The components of the value τ_i are given above. It is obvious that the main factor determining the average duration of the τ_{cp} cycle is the passenger traffic (PT) $A_{п.л}$. This indicator is one of the specified values set by the corresponding standard [1]. The initial average passenger traffic according to [1] is determined by the formula:

$$A_{1p} = 12 \cdot A_{п.л} \cdot \frac{(N - N_H) \cdot Y}{100N}, \quad (12)$$

where $A_{п.л}$ — the number of passengers in the building or blocks of flats using the elevator,

$$A_{п.л} = (N - N_H) \cdot C_{KB} \cdot d_{KB}, \quad (13)$$

N — the number of occupied floors; N_H — the number of floors, tenants of which do not use the elevator (usually $N_H=1$); Y — the indicator of PT intensity, characterizing the number of people to be transported within a five-minute interval, in percentage terms of the number of people using the elevator ($i=4-8\%$); C_{KB} — the average number of apartments on one floor; d_{KB} — the number of people per apartment, using the elevator; according to [1] this figure is recommended in the range of 1, 2-3.

The analysis shows that the application of the indicator d_{KB} to all elevators leads to incorrect results: the average number of residents in a single apartment $d \leq d_{KB}$.

It is logical to assume that the number of residents using the elevator is proportional to the total number of residents of the riser blocks of flats or building. In this case, the calculation will not be related to the value d_{KB} — the average number of residents of a separate apartment who use the elevator. It is more reasonable to enter a single conditional indicator in expression (13), which depends only on the number of residents of a given building or riser blocks of flats. Each building or riser blocks of flats must be characterized by individual indicators: the number of building floors N , the total (list) number of residents Z and a single indicator — the share of the number of residents using the elevator $d_{ж.л}$. Then the number of passengers of building or riser blocks of flats using the elevator $A_{п.л}$, can be determined by the formula:

$$A_{п.л} = Z \cdot \frac{M_k - M_{1k}}{M_k} \cdot d_{ж.л}, \quad (14)$$

where M_k — the total number of apartments in the building (blocks of flats); M_{1k} — the number of apartments in the building (blocks of flats), tenants of which do not use the elevator.

Then, taking into account recommendations [1] and the proposed changes, the estimated hourly passenger traffic can be determined by the formula:

$$A_{1p} = 0,12 \cdot Z \cdot \frac{M_k - M_{1k}}{M_k} \cdot d_{жд} \cdot \frac{(N - N_H) \cdot Y}{N}. \quad (15)$$

The calculated average minute PT will be:

$$A_{1p} = 0,002 \cdot Z \cdot \frac{M_k - M_{1k}}{M_k} \cdot d_{жд} \cdot \frac{(N - N_H) \cdot Y}{N}. \quad (16)$$

Expression (16) provides a formula for calculating the average cycle duration. To do this, we will enter the average cabin capacity rate in the r_{cp} cycle. The value r is random, the distribution series of which is established experimentally. The data on the distribution series are given in [5], for most cases at $R=5$ people $r_{cp}=2.25$, $R=8$ $r_{cp}=2.85$.

The estimated average duration of the cycle τ_{cp} (min/cycle) is defined as the quotient of the average cabin capacity in the r_{cp} cycle divided by the average minute cargo flow A_{1p} , i.e.

$$\tau_{cp} = r_{cp} / A_{1p}. \quad (17)$$

After simple transformations, we get:

$$\tau_{cp} = \frac{500 \cdot M_k \cdot N \cdot r_{cp}}{Z \cdot (M_k - M_{1k}) \cdot d_{жд} \cdot (N - N_H) \cdot Y}. \quad (18)$$

Expression (18) allows us to make a qualitative assessment of the influence of the main factors on the cycle duration that provides a given passenger flow. If we assume that the ratios $N/(N - N_H)$ and $M_k / (M_k - M_{1k})$ are close to one, then the main influencing factors are the capacity level of the cabin with passengers r_{cp} (proportional dependence) and the conditional design number of passengers using the elevator, $Z \cdot d_{жд} \cdot Y$ (inversely proportional dependence).

A set of mathematical models (4), (5), (11) and (18) allows us to calculate the average values of the main kinematic characteristics of the elevator operating mode, as well as to obtain all the necessary initial data to start the simulation process. Let us consider the procedure for calculating the average values of the machine time coefficient K_{mcp} , the specific number of swithes on of the main drive per NMT minute n_{cp} and the duration of the pause before the next cycle Δ_{cp} .

It is well known, that K_{mcp} is the ratio of the elevator's NMT per cycle τ_{mcp} to the total average value of the duration of the cycle τ_{cp} — formula (18). The calculation of τ_{mcp} is a separate task for analyzing the general operating mode of the elevator over a long period of time. As shown above, there are three main cycles — A, B and A+B, in each of which the average value of the NMT is determined by individual ratios: for cycles A and B — this is formula (5), for cycle A+B — formulas (1) and (11). To calculate the average value τ_{mcp} , it is necessary to additionally set the ratio of the share of each of the cycles in the overall structure of the mode. The parts of cycles of different types we denote γ_A , γ_B and $\gamma_{(A+B)}$, respectively, with $\gamma_A + \gamma_B + \gamma_{(A+B)} = 1$. Cycles of type A — the elevator moves mainly to the first floor, morning mode, type B — evening mode, type A+B — day and night modes. The average duration of the NMT at different speeds for all elevators (regardless of the number of floors of the building) can be determined by the formula:

$$\tau_{mcp} = \frac{h}{60v(N)} [(\gamma_A + \gamma_B) \cdot (N + 2) + \gamma_{(A+B)} \cdot K_{np(A+B)cp}], \quad (19)$$

where $K_{np(A+B)cp}$ — is calculated by the formula (11); $v(N)$ is the dependence of the accepted elevator speed on the number of floors of the building.

Expression (19) indicates that under the known cycle alternation mode, the value of the average NMT depends primarily on the number of floors of the building and the speed of movement of the elevator cab. For example, in Fig. 4, (Graph a), the dependence $\tau_{mcp}=f(N)$ is given at $(\gamma_A + \gamma_B) = 0.8$, $v=1$ m/s; in Graph b, the change in NMT at the cab speeds corresponding to the number of floors of the building is shown in Fig. 3b.

Mathematical model of a random variable — the duration of waiting for the next cycle. These data can be used to justify the initial parameters for the simulation process. For a full-scale implementation of the cycle-by-cycle simulation process, knowledge of the functions or distribution density of random variables is required, a list of which is presented in the introductory part of the article. The distribution series of discrete quantities M , L , S and the absolute

value of the difference $|M-L|$ are considered above. The method for calculating and modeling the random number of elevator stops when moving with passengers up from the first floor is given in the work of D.S. Apryshkin and G.Sh. Khazanovich "Methodology and algorithm for simulating the operating modes of a passenger elevator" [5]. Let us consider the determination of a random waiting time for the next cycle Δ .

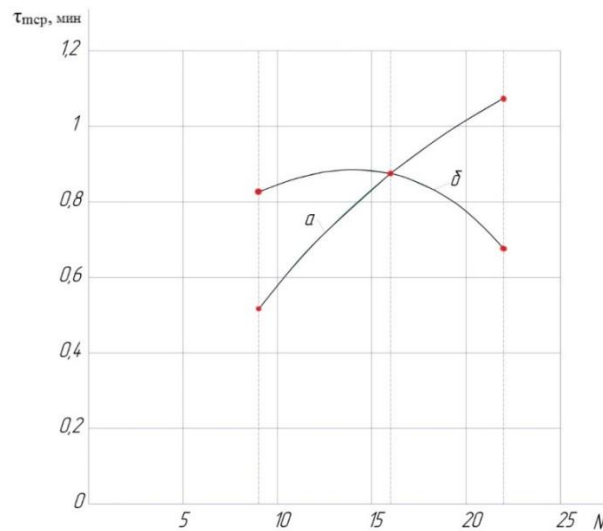


Fig. 4 Influence of the number of floors of a residential building (N) on the average values of the NMT cycle

The ratio between the time elements of the cycle gives the ratio

$$\tau = (\Delta + \tau_m + \tau_{пз}), \quad (20)$$

where $\tau_{пз}$ — the total time spent on passengers loading and unloading.

Moving on to the average values, we get

$$\Delta_{ср} = \tau_{ср} - \tau_{мср} - \tau_{пзср}. \quad (21)$$

The average values of the components $\tau_{ср}$ and $\tau_{мср}$ are calculated using formulas (18) and (19), respectively.

The total time $\tau_{пзср}$ depends on the number of stops $F_{нз}$ and the average duration of one stop $t_{1.пз}$

$$\tau_{пз} = F_{нз} \cdot t_{1.пз}. \quad (22)$$

The number of stops in the cycle consists of the final stops $F_{нзк}$ and intermediate stops $F_{нзи}$ and depends on the type of movement — A, B or A+B. When the elevator is moving down, there are no intermediate stops, the number of final stops for cycles of any kind is equal to two, i.e. $F_{нзк}=2$. The number of intermediate stops during the upward movement of the elevator is determined by the method described in [5].

The random variable Δ , as an element of the queuing system, is modeled according to the exponential law with the parameter $\Delta_{ср}$ [6– 7]. The probability density has the form:

$$f(\Delta) = \frac{1}{\Delta_{ср}} e^{-\frac{\Delta}{\Delta_{ср}}}. \quad (23)$$

Capacity of the elevator unit. The mathematical models of the elevator functioning processes justified above allow us to solve the problem of determining the maximum capacity of the unit, Q_{np} , people/hour. The basis is the duration of the combined cycle NMT (A, B, A+B) in total with the duration of stops for passengers loading and unloading, as well as the average number of passengers transported per cycle, i.e.

$$Q_{np} = \frac{60 \cdot d_{ср}}{\tau_{мср} + \tau_{пзср} + \delta}, \quad (24)$$

where δ — admissible waiting time for the next cycle, not more than one minute; $\tau_{мср}$ is calculated by \ formula (19); $\tau_{пзср}$ — is calculated by formula (22).

Expression (24) allows us at the design and selection of an elevator unit stage to analyze the impact of critical factors on its average capacity — the number of floors, speed and capacity of the cabin. The obtained values Q_{np} should be compared with the estimated hourly passenger flow $A_{1p}(16)$ and we should determine the safety margin of the ПППП.

Calculation of the indicator of transport comfort of the elevator unit. First of all, it is necessary to establish the average possible interval of movement of the cab from the first floor of the building [1]. In accordance with the notation, it is necessary to calculate the average interval of B cycle at a known frequency of these cycles γ_B . If we determine the average NMT of B cycle, in accordance with (5) and take into account the loss of time for doors opening and closing according to (22), the average time after which the lift will be in position before lifting from the ground floor, will be:

$$\tau_{TK} = \frac{1}{\gamma_B} \left[\frac{h(N+2)}{60v(N)} + F_{\Pi B.B} \cdot t_{1.\Pi B} \right] + \delta_1, \quad (25)$$

where τ_{TK} — the average indicator of transport comfort of the elevator, min.; $F_{\Pi B.B}$ — the average number of stops at lift motion in a B cycle from the first floor; δ_1 — the conditional waiting time for the next cycle (10 sec.).

To assess the current level of transport comfort in the modeling process, in the numerator of formula (25) instead of $(N+2)$, the actual number of stairs is inserted, passed by the elevator in B cycles from the first floor, Δ_B :

$$\tau_{TKB} = \frac{1}{\gamma_B} \left[\frac{h \cdot \Delta_B}{60v(N)} + F_{\Pi B.B} \cdot t_{1.\Pi B} \right] + \delta_1. \quad (26)$$

As it can be seen from expression (25), the calculated average index τ_{TK} depends on the number of floors of the building, the average speed of the cabin, the number of stops with passengers loading and unloading, and the specific number of B cycles in the total number of cycles. The result of the calculation according to formula (25) characterizes the transport comfort of the elevator unit for the entire daily period of its operation. To assess the transport comfort during the hours of the highest load of the elevator with B cycles (the so-called evening mode), the share of this mode is significantly increases (Table 2).

To assess the level of transport comfort, boundary values are introduced: up to 60 s. — excellent, 60-80 s. — good, 80-100 s. — satisfactory. As it can be seen in the table, it is impractical to evaluate the average values of the level of transport comfort, since the calculated indicators are significantly lower than those established by the standard. For the evening mode, the values of $\tau_{TK.beq.}$ are close to good or satisfactory values. The main means of increasing the level of transport comfort of the elevator is to increase the average speed.

Table 2

Calculation of the values of the transport comfort indicator of standard elevators

N	v,m/s	$F_{\Pi B.B}$	$t_{1.\Pi B},c$	$\gamma_{B.cp}$	δ_1, c	$\tau_{TK.cp},c$	$\tau_{TK.beq.}, c$
				$\gamma_{B.beq}$			
9	0.63	2	8	0.4	10	180.5	80.2
				0.9			
16	1.0	2	8	0.4	10	185.5	82.4
				0.9			
22	1.6	2	8	0.4	10	163.4	72.6
				0.9			

When calculating and analyzing the main indicators of elevator units, the requirements of regulatory documents were taken into account [1–2, 8–10].

The structure of the algorithm for modeling the operating modes of the elevator in order to assess the capacity and transport comfort. The description of a complete algorithm for simulating elevator operating modes is a complicated task. In this regard, the structure of the algorithm and brief explanations to it are given below (Fig. 5).

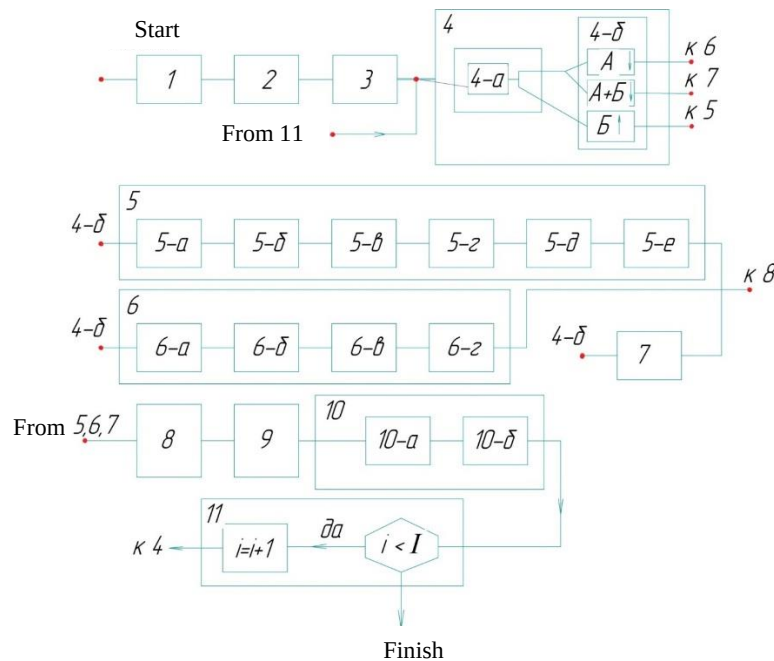


Fig. 5. The structure of the algorithm for simulating the operating modes and the indicator of transport comfort of the elevator unit

The simulation procedure consists of the following main blocks:

1 — input of the initial data, which are divided into groups: characteristics of a residential building, elevator unit and general characteristics of the mode — $N, N_H, h, Z, d_{жл}, M_k, M_{k1}; v, R; Y, \gamma_A, \gamma_B, \gamma_{A+B}, d_{cp}, F_{пБ}, t_{пБ}, \delta, I;$

2 — calculation of the average initial indicators necessary for modeling the duration of the pause between the cycles of the Δ_{cp} (21), the transport comfort indicator τ_{TK} (25) and the capacity of the elevator unit Q_{np} (24): $K_{np(A+B)cp}$ (11), τ_{cp} (18), τ_{mcp} (19), $\tau_{пзcp}$ (22), n_{cp} (2), A_{1p} (15);

3 — input of the initial conditions: cycle number i , elevator standing floor L_i ;

4 — determination of a random cycle in accordance with the direction of motion (4-a), distribution $\gamma_A, \gamma_B, \gamma_{A+B}$: A, B or A+B (step 4-b);

5 — when moving up from the first floor (cycle B) — simulation of the destination floor number S_i (5-a), calculation of the number of spans $K_{npi} = (L_i - 1) + (S_i - 1)$ — (5-b), the number of final stops F_{ki} (5) and simulation of the number of intermediate F_{n1} stops (5-d), calculation of the cycle NMT τ_{mi} by formula (1) and the specific number of switches on n_i according to formula (2) — (step 5-e), calculation of the current transport comfort by formula (26) — (step 5-f) [5];

6 — when moving down to the first floor from any floor M (series A): simulation of the random number of floor call M_i (6-a), calculation of the number of spans $K_{npi} = (|L_i - M_i|) + (M_i - 1)$ — (6-b), the number of final stops F_{ki} — (6-c) and calculation of the cycle NMT τ_{mi} by formula (1) and the specific number of switches on n_i according to formula (2) — (6-d);

7 — when moving down to the first floor from any floor M when the elevator is standing on any floor L (cycle A+B) simulation is performed in the hotel subroutine;

8 — at the end of the i -th cycle, the main kinematic indicators τ_{mi}, n_i and the final floor of the elevator L_{i+1} are fixed;

9 — a random value of the pause between cycles Δ_i is modeled according to formula (23);

10 — summers of kinematic indicators $\tau, \tau_m, n, \tau_{TKB}$ and transport comfort indicator τ_{TKB} are formed (step 10-a), and the average values for i cycles are calculated (10-b);

11 — the condition $i < I$ is checked; when it is executed, the number of the next cycle $i+1$ is entered, and the simulation continues from step 4.

The results of the simulation will be presented in the next issues of the journal.

Conclusion. The current issues of establishing the main indicators of capacity and transport comfort of elevators of residential buildings are considered. These indicators determine the safety and usability of elevator units. Despite the existence of a number of state standards regulating the main parameters of passenger elevators, these documents do not reflect the issues of the formation of kinematic indicators and transport comfort of elevator units as a random process. In the course of the study, the following results have been obtained, the conclusions have been made:

The general problem of the elevator cycle-by-cycle operation is formulated with the identification of the influencing factors as random variables.

Adequate mathematical models for the formation of elevator drive load indicators have been developed, which allow determining the current and average values of the machine time coefficient and the specific number of switches on.

For the first time, the formulas for calculating the number of spans passed by the elevator in mixed modes are justified. Universal dependencies of the distance passed on the number of storeys of the building are established.

The relationship between passenger traffic, residential building density, and cycle duration is studied, and the ratio is obtained for the average cycle duration that provides a given elevator capacity.

The mathematical model of the waiting time for the next cycle is justified, which makes it possible to conduct a cycle-by-cycle simulation of the process.

The formula is obtained for calculating the maximum capacity of the elevator, which takes into account the duration of operation in net machine time and the average degree of the elevator cab capacity.

A mathematical model has been developed for calculating the main indicator — the transport comfort of the elevator unit. The most important influencing factors are identified.

The structure of the algorithm for simulating the operating modes of elevators has been developed in order to establish the capacity and transport comfort.

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Contribution of the authors:

D. S. Apryshkin — formulation of the purpose and program of the research, derivation of mathematical models, development of simulation algorithm; G. S. Khazanovich — study of the basic modes of operation of elevator units, the influencing factors rationale, consultation in the derivation of mathematical models, algorithm development.

Ensuring safety during operation of a loading and unloading railway overpass at an oil depot**A. V. Fedosov, N. Kh. Abdrakhmanov, A. S. Tikhonova, I. R. Danieva, R. R. Valeeva**

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Introduction. The analysis shows that one of the main causes of accidents at refineries is the low reliability of process equipment and technological discipline violation.

Problem Statement. The objective of this research is to study theoretical foundations of loading and unloading railway overpass operation, to identify hazardous factors and to suggest measures to improve safety during operation of this overpass at the oil depot of Bashneft-roznitsa OOO (limited liability company).

Theoretical Part. During loading and unloading operations, many accidents occur annually that pose some risk to workers life and health and cause damage to the ecology and economy of the country. The features of the process are: high pressure, high temperature, the use of dangerous and harmful, toxic chemicals that have a harmful effect on humans.

Technical causes of accidents are wear and unreliability of equipment, violation of production discipline. However, there are also organizational causes of accidents, such as poorly organized production control, as well as low level of industrial safety competence of employees.

Therefore, it is necessary to carry out measures aimed at improving the reliability of the equipment.

The study has also revealed that one of the main technical causes of accidents at oil refining enterprises is the low reliability of technological equipment and violations of production discipline.

Conclusion. The paper presents the study on operation of the loading-unloading railway overpass at the oil depot of Bashneft-roznitsa OOO (limited liability company). There have been developed and proposed measures to improve safety during operation of the loading-unloading railway overpass at the oil depot of Bashneft-roznitsa OOO (limited liability company).

Keywords: security provision, loading-unloading railway overpass, accident, reliability, production discipline, refining.

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Introduction. At the enterprises of the oil refining industry, the compliance with industrial safety is considered as one of the most important tasks, which covers a wide system of technical, sanitary, hygienic, legal and economic measures coordinated to ensure safe and harmless working conditions. Ensuring industrial safety covers all aspects that relate to the activities of the enterprise. Only by following all the rules and requirements of industrial safety, you can organize an effective production.

Problem Statement. The main objective is to increase the operation safety of loading and unloading railway overpass at the oil depot of Bashneft-roznitsa OOO (limited liability company), for which it is necessary to study the theoretical foundations of the operation of loading and unloading railway overpass at the tank farm, to identify hazards in the operation of loading and unloading railway overpass, to propose measures to increase operation safety.

Theoretical Part. Having studied the publicly available statistics of accidents and injuries, it can be concluded that the main reasons for their occurrence at oil refining enterprises are low reliability of technological equipment and technological discipline violation (Fig. 1) [1]. During the study of statistical data, it was noted that the main

organizational causes of accidents are poorly organized production control (PC) and a low level of knowledge on industrial safety (IS) by the employees of the enterprise [2].

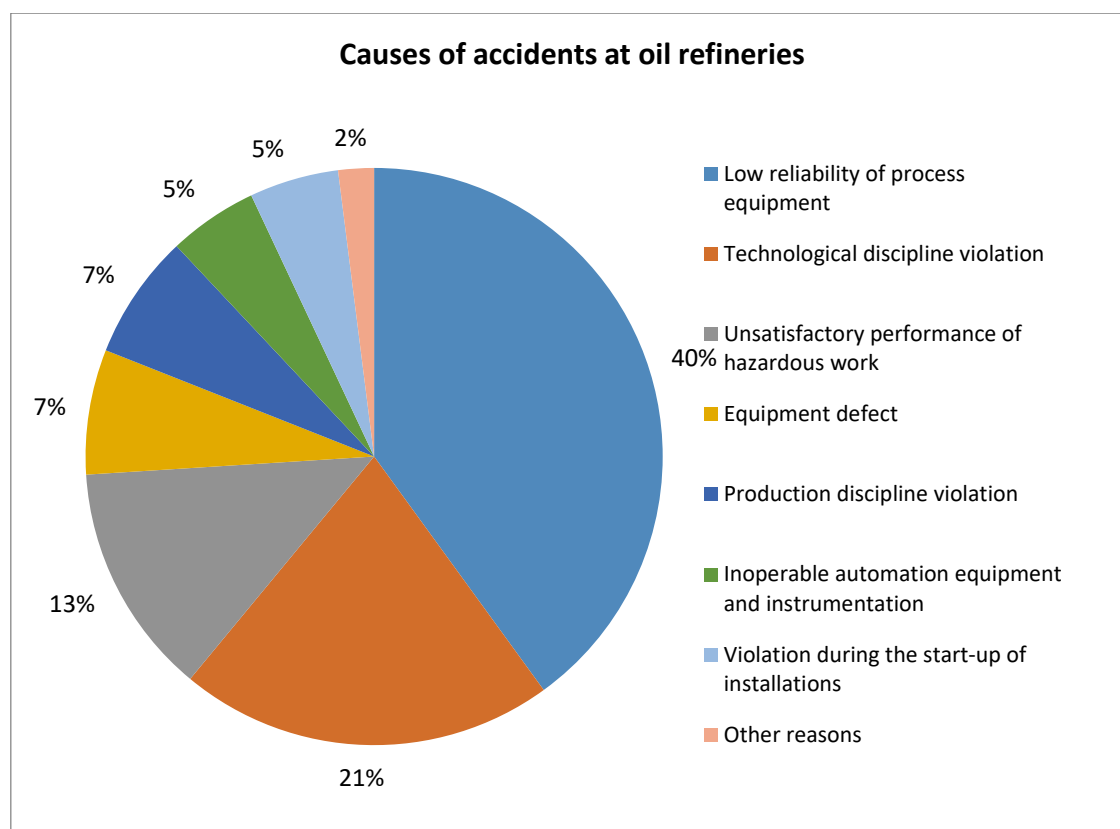


Fig. 1. Causes of accidents at oil refineries

Loading and unloading railway overpasses are designed for loading motor gasoline, diesel fuel, heating oil-100, vacuum gas oil, jet engine fuel (JF), aviation gasoline, as well as for unloading with subsequent pumping into freight fleets or directly into tank cars of motor gasoline, diesel fuel, fuel oil, vacuum gas oil. The production facility includes the following blocks: a 300-meters-long light oil products loading and unloading railway overpass, a 300-meters-long dark oil products loading railway trestle, a dark oil products unloading overpass, a six-car railway draining overpass (21-th railway track), horizontal underground tanks E-1 and E-2, buried at 4.0 m, cylindrical [3].

Technological operations are performed at the oil depot of Bashneft-roznitsa OOO (limited liability company), such as placing tank cars in the loading area, preparing for loading, oil products loading, finishing loading, placing tank cars in the unloading area, preparing for unloading, oil products unloading, finishing unloading, pumping light oil products from buried tanks E-1, E-2.

After studying the technological process, the authors have identified a operating failures that could lead to accidents: absence of oil supply in the centrifugal submersible pump after switching on; submersible pump does not provide the necessary performance; vibration and noise when the submersible pump is leaking oil through the seals or flange joints; oil products at the loading are not received or stopped at the wagon-tank; overflow of drainage channels; visible leakage of oil from hose; doors from the exit platform to the cars do not open or are difficult to open [4-5].

First, in order to increase the level of operation safety of the loading and unloading railway overpass at the oil depot of Bashneft-roznitsa OOO (limited liability company), it is necessary to exclude the most likely causes of accidents. It is necessary to carry out measures aimed at improving the reliability of the equipment. It includes:

- putting into operation modern equipment;
- use of pipes and joints of higher quality (modern material makes it possible to increase the level of industrial safety. An example of such a material is Asmol. This material has an incredible resistance to the negative

effects of corrosion and aggressive environments. Asmol is an asphalt-tar oligomer. The material is get from petrochemical production waste. Functional groups of Asmol (in contact with a metal surface) interact with the crystal lattice of the metal, forming a strong and reliable complex of iron-petroleum polymer);

- use of equipment that transmits signals, an excellent example of it is "Buran-1 CD". This alarm system has the ability to instantly determine the amount of gas contamination during work;

- the employees who carry out repairs and maintenance of equipment must be qualified. In case of an accident, the personnel must do the necessary activities in a particular order [6-7];

- the equipment used in the working process of the enterprise must be subject to industrial safety expertise. At the enterprises using loading and unloading equipment, the expertise should be carried out in the following situations:

- a) if there were repairs, during which the design of the equipment was changed or the main materials were changed, if it became possible to return the equipment to the technological process after a serious accident;

- b) when using old equipment (more than 20 years of use) without technical documentation;

- c) if the regulatory and technical document of this organization does not meet the existing safety requirements;

- d) if the period of use of the loading and unloading equipment, which was determined by the manufacturer, has ended, as well as when the permissible operating cycles approach zero [8];

- introduction of the automated process control system (APCS) for the automatic and operational control of the equipment on a railway overpass for loading and unloading of various refined products. The TPA system (APCS) is made using three programmable logic controllers (PLCs) SIE-MENS SIMATIC S7-300 series. The system performs the following functions:

- automated management of loading and unloading of refined products with the established operating methods;

- remote control of the overpass equipment;

- control, as well as data counting;

- getting timely information about the state of the units;

- automatic transfer of data to the "1C: Accounting" system

- manual management of loading and unloading processes;

- automatic emergency protection;

- automatic fire protection.

The system architecture contains the following subsystems: EP — emergency protection, TPA — process automation, AFE — automatic fire extinguishing (Fig. 2).

Each of these subsystems includes three levels:

- field level consists of instrumentation and automation (max level sensors, sensors of position, control over the lower concentration limit of flame propagation, flow meters);

- the lower level consists of programmable logic controllers (PLCs) that provide remote control of equipment, intermediate links, and signal input/output modules.

PLCs are necessary for performing such functions as:

- collecting information about the current state of absolutely all devices, as well as system units and their control mode;

- formation of information notifications about all modifications in the system, management commands and the results of their implementation;

- receiving operator commands;

- automatic control over the devices and aggregates according to the approved algorithms of operation;

— an important component of the third, upper, level is the man-machine interface, represented by the SCA-DA system.

Functions of the third level:

- control over the devices that receive the control signal and act on the control object through the working body or directly;
- registration of available information;
- control over the peripheral devices;
- storage of information.

The best system construction is carried out if the automated work areas are located in the operator room, and the controllers are located directly on the overpass, in specially designed explosion-proof cabinets. Thus, the connection of devices and aggregates with the controller is achieved by the shortest cable length [9].

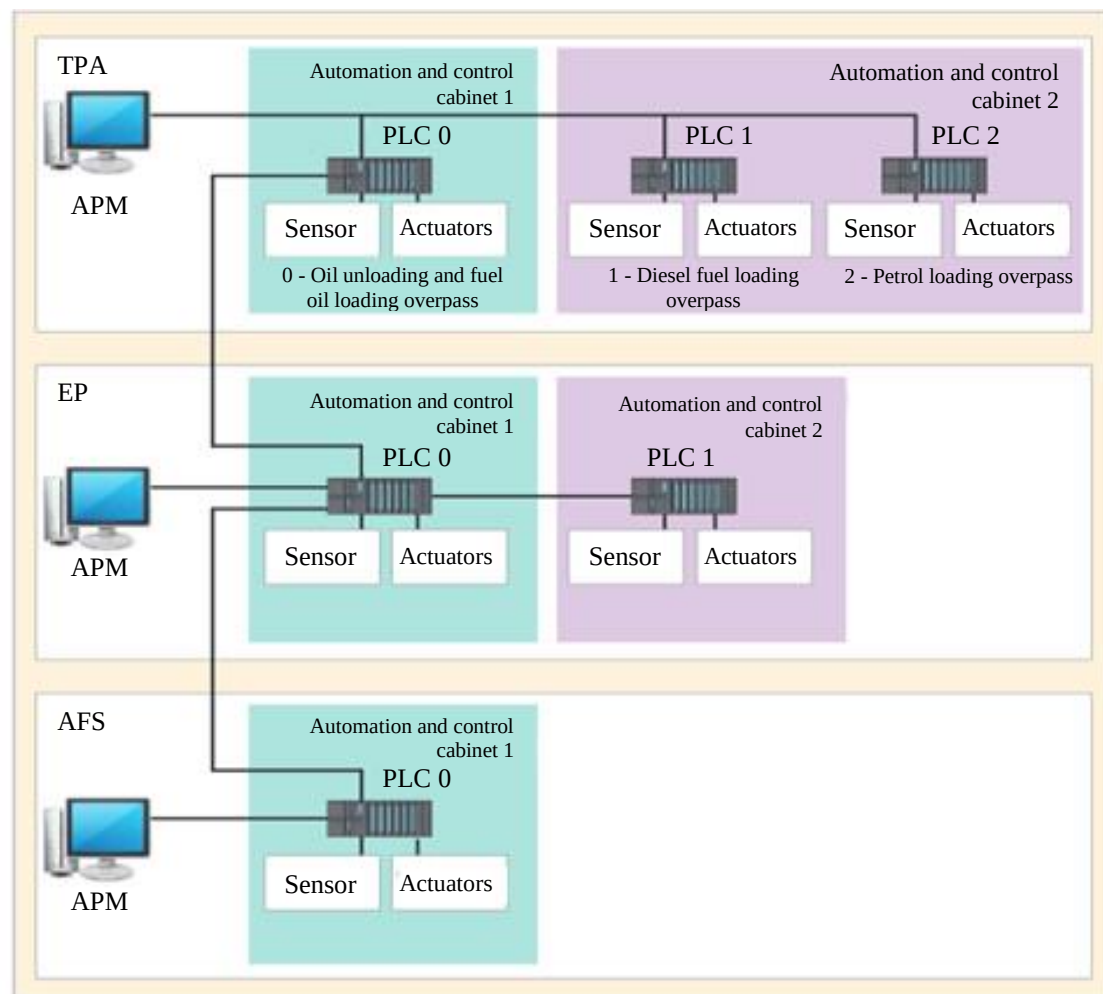


Fig. 2. Architecture of the automated control system of the railway overpass: TPA — automation of the technical process, EP — emergency protection, AFS — automatic fire suppression

It is also necessary to exclude the second most likely factor in the occurrence of an accident at work — violation of technological discipline. To improve the technological discipline, it is required to:

- equip the workplaces with the necessary equipment and tools;
- stiffen daily, special and periodic monitoring;
- think through a system of employee motivation and incentives for compliance with the technological discipline. Incentive measures can be anything: bonuses and allowances (material), certificates of honor and state awards (non-material). Incentive measures develop employees' interest in the proper implementation of the

requirements for technological discipline, and employees also have attitudes to comply with these requirements. There is the difference between the stimulating management, which is used for the promotion of the employee, and the punishing management used to increase staff accountability for their actions/inaction, since for non-compliance with the technological discipline by the employees, they are brought to disciplinary responsibility with the bonus loss [10].

It is necessary to motivate employees with various unconventional methods. Here are some of them:

a) first of all, to encourage by personal example. After studying the statistics, we can say that the cause of all the troubles is often low motivation to perform a certain type of work. An excellent way to increase motivation will be the introduction of uniform standards for all employees of the enterprise;

b) a person has such a feeling as conscience, if you correctly use it, you can achieve an increase in technological discipline. You can hold competitions between the "leaders" in the number of violations of the technological discipline and identify the "winner", and then place a list of those who distinguished themselves on the entrance hall or on the organization's website;

c) at the same time, we must not forget about the employees who try not to violate the technological discipline. It is necessary to encourage their behavior, so that the impulse does not fade away;

— the control over the fact that employees themselves do not make changes to the established technological process (they have the opportunity to make proposals for the rationalization of the technological process in the office of working invention);

— it is necessary to create conditions in which employees can improve their professional skills;

— it is recommended to hire employees on a competitive basis [11].

Great attention is given to the technological discipline in any enterprise, and its non-compliance is not only prohibited, but also punished [12].

Conclusion. The main causes of accidents during the operation of the loading and unloading railway overpass are the low reliability of technological equipment and technological discipline violations. When implementing the measures to improve the operation safety of loading and unloading railway overpass proposed in this article, the probability of an emergency will be reduced, and the negative impact on the environment and economic damage will be minimal.

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I. R. Danieva and R. R. Valeeva — theoretical research and patent analysis; N. Kh. Abdrakhmanov — formulation of the main idea of the research and article structure, editing; A. V. Fedosov and A. S. Tikhonova — literary, patent analysis and participation in theoretical research.

Improvement of warehouse hovercraft transport devices with inclined feed channels

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Introduction. The paper considers the question of the directions of mechanization and automation of rack warehouses logistics. The paper considers hovercraft transport devices operating in the storage area with inclined feeding channels. The displacement of the load center relative to the geometric center of the support surface is studied. It is noted how this affects the main characteristics of the studied devices.

Problem Statement. Previous studies have proved the sufficient performance of non-powered hovercraft transport devices with inclined feed channels, their safety and efficiency in the transportation of piece goods, as well as the potential for mechanization and automation of transport and storage operations in rack warehouses. The task of this work is to present a scheme of mechanization for the storage area of a rack warehouse equipped with a transport device with inclined feeding channels.

Theoretical Part. In rack warehouses designed for the storage of individual goods, the receiving, storing and sending operations are in most cases carried out using carrying and lifting machines. Stacker cranes are most common, but their use requires the creation of complex and expensive systems, i.e. significant capital and operating costs. The article considers the system of mechanization of a rack warehouse with the use of hovercraft vehicles with an off-center location of the cargo. In this case, the height of the airbag depends on the eccentricity of the load location. The points of application and the values of the resistance and traction forces, torques and friction forces that affect the total resistance are shown, which are typical for such a situation

Conclusion. The results of the research allow us to state that in some cases, instead of traditional transport devices, the use of hovercraft transport devices with the inclined feed channels is effective in logistics enterprises.

Keywords: air bag, rack warehouses, load center, load conveyor.

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Introduction. Storage-retrieval work in rack warehouses can be successfully mechanized with the help of non-powered hovercraft transport devices with inclined feed channels. Their sufficient operability, safety and efficiency in the transportation of piece goods have been proven. The authors of [1-4] assumed the same height of the air cushion at all points between the bearing surface of the transport device and the supporting surface of the load. However, this is only possible if the gravity center of the load is located above the geometric center of the support surface, so this approach can only be considered as a special case. Thus, the application of the methods presented in [1-4] for determining the main parameters of transport devices with a significant shift in the gravity center can lead to the creation of an inoperative structure.

Problem Statement. The task of this work is to present a scheme of mechanization for the storage area of a rack warehouse equipped with a transport device with inclined feed channels. In this case, it will be established how the displacement of the gravity center of the load relative to the geometric center of the support surface affects the main characteristics of the devices under consideration.

Theoretical Part. Figure 1 shows the scheme of mechanization of the rack warehouse. [5]

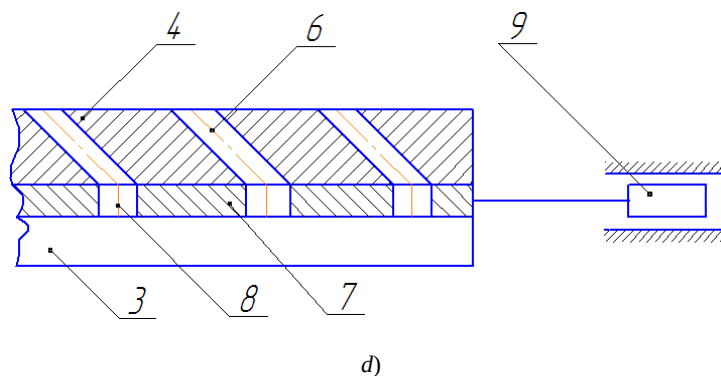
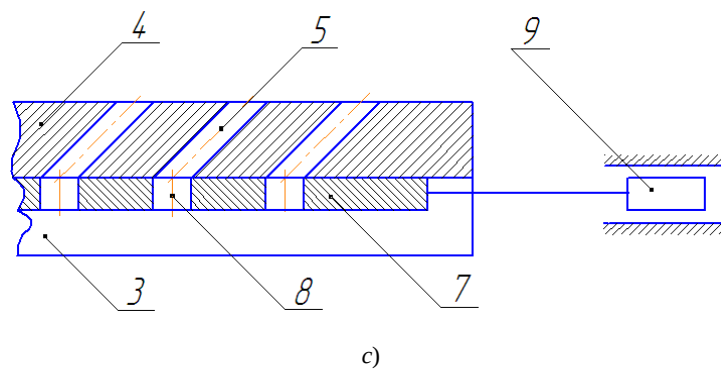
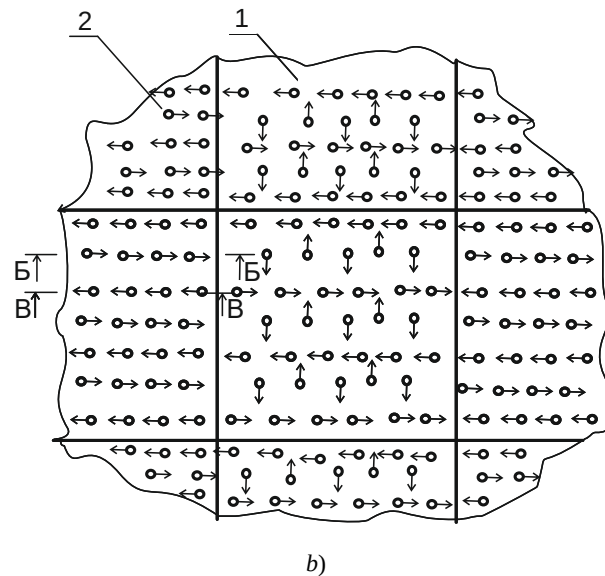
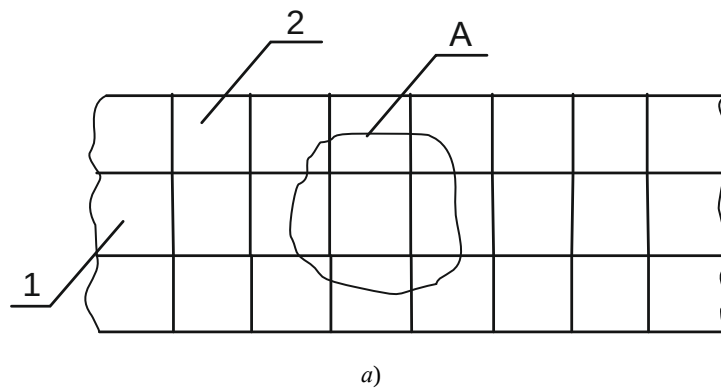


Fig. 1. Scheme of mechanization of a rack warehouse using hovercraft transport devices: top view (a), view A (b); section B — B (c); section B — B (d); 1 — transport conveyor; 2 — rack cell; 3 — receiver chamber; 4 — bearing plate; 5, 6, 8 — feed channels; 7 — control plate; 9 — control device

The floor of the cargo storage rack is:

- longitudinal transport conveyor 1 with air cushion,
- cell 2.

The cell consists of:

- receiver chamber 3,
- bearing plate 4 (its feed channels tilt in both directions),
- control plate 7 with vertical feed channels 8.

The control plate is driven by the device 9 (pneumatic cylinder, solenoid, electromagnet, etc.).

When releasing a pallet with a load from the cell 2 of the rack, the control plate 7 is installed using the device 9 in such a position that the supply channels 5 are open and the channels 6 are closed. The air, which is under pressure in the receiver chamber 3, enters through the supply channels 8 and 5 under the support surface of the pallet. An air cushion is created between the bearing plate 4 of the rack cell 2 and the support surface of the pallet. Due to the action of inclined air jets, the pallet with the load is moved to the conveyor 1. The installation of pallets in the cells 2 of the rack is carried out in the reverse order. In this case, the inclined feed channels 6 are open, and the channels 5 are closed. With the help of an elevator-type lift (or any other lift), the pallet with the load can be transferred from the transport conveyor of the floor to the ground transport. The number of floors in the rack is not limited.

Let us consider a non-driven conveyor with the air cushion and inclined feed channels. In this case, the movement of the pallet with the load is possible only if the following conditions are met:

$$F_x \geq W_0 + W_u = W_0 + G \cdot \frac{a}{g}.$$

where F_x — the traction force created by the inclined jet of air; W_0 — the resistance to movement of the pallet with the load; W_u — the force of inertia during acceleration of the load to the required speed; G — weight of the pallet with the cargo; a — the acceleration of the pallet with the cargo, to achieve the required speed at the specified time; g — gravity acceleration.

The authors of previously published works^{1,2} and methods for calculating [4] the main parameters of air-cushion conveyors assumed that the resistance to movement was equal to the sliding resistance of the support surface of the pallet (load) on the bearing surface of the conveyor. Moreover, the height of the air cushion at all points was assumed to be the same, which is possible only if the gravity center of the load is located above the geometric center of the pallet.

However, the load may not be located in the center of the pallet, i.e. the center of gravity of the load does not coincide with the geometric center of the support surface of the pallet. In this case, the height of the air cushion under the pallet is different and depends on the eccentricity of the load location. Because of this, the points of application are shifted and the values of the drag and traction forces change, which depend on the height of the airbag. In addition, there are torque effects that tend to turn the pallet, which moves in the guide rails that limit its transverse displacement and rotation. At the points of contact of the pallet with the guides, friction forces arise that increase the total resistance (Fig. 2).

¹ Rabochiy G. M., Romyantsev B. P. Opredelenie nesushchey sposobnosti ustroystv dlya beskontaktnogo peremeshcheniya gruzov [Determination of the load-bearing capacity of devices for contactless movement of goods]. Novoe v pod'emno-transportnoy tekhnike: tez. Vsesoyuz. nauch. konf., posvyashch. 60-letiyu kafedry "Pod'emno-transportnye mashiny i oborudovanie" MVTU im. N. E. Bauman [New in lifting and transport equipment: proc. of All-Union. scientific conf., dedicated to the 60th anniversary of the Department "Lifting and Transport Machines and Equipment" of the Bauman Moscow State Technical University]. Moscow. 1985. p. 36–37 (In Russ.).

² Bshesh N. Yu. Sovershenstvovanie konveyerov s vozdushnoy podushkoy, transportiruyushchikh shtuchnye gruzy: dis. ... k-ta tekhn. Nauk [Improvement of air-cushion conveyors transporting piece loads: authors thesis]. Lugansk, 1994. 179 p. (In Russ.).

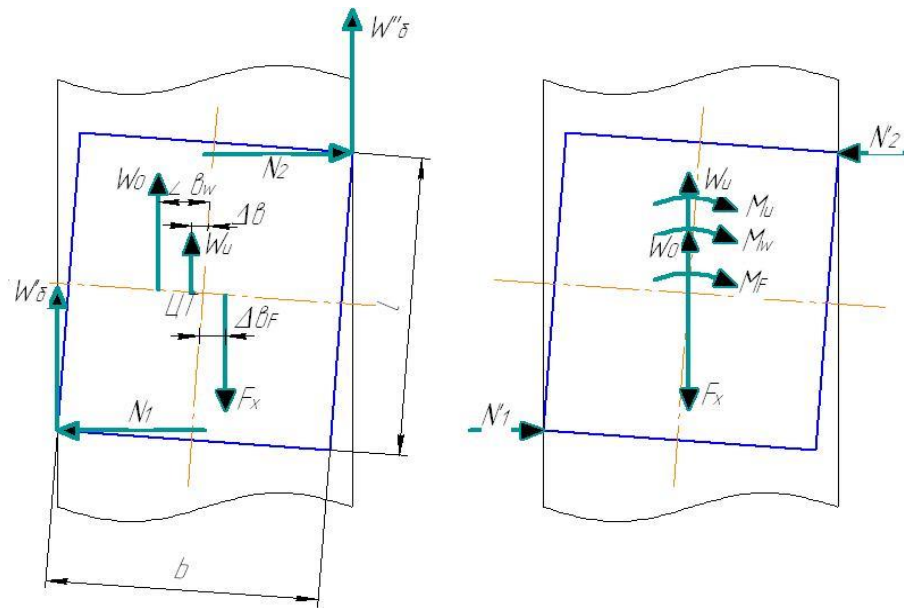


Fig. 2. Total resistance of the movement of the pallet with the load

Thus, the resistance to the movement of the pallet:

$$W_o = W_c + W_\delta,$$

where W_c — the resistance from the pallet sliding on the bearing surface of the conveyor, W_δ — the resistance from friction against the guide rails.

The slip resistance can be determined by the formula:

$$W_c = G \left(f_1 \cdot e^{-\frac{6h}{\Delta}} + 0,0008 \right),$$

where G — the coefficient without the air cushion, h — the height of the air cushion, Δ — the height of the unevenness of the bearing surface of the conveyor.

Resistance from friction against the guide rails:

$$W_\delta = W'_\delta + W''_\delta = (N_1 + N_2) \cdot f_2 = 2 \cdot f_2 \cdot \frac{M_F + M_w + M_u}{\ell}.$$

where M_F — the moment caused by the displacement of the traction force; M_w — the moment caused by the shift of the slip resistance; M_u — the moment caused by the displacement of the inertial forces during acceleration; ℓ — the length of the pallet.

$$M_F = F_x \cdot \Delta b_x,$$

$$M_w = W_c \cdot \Delta b_w,$$

$$M_u = \frac{G}{g} \cdot a \cdot \Delta b,$$

where Δb_x , Δb_w , Δb — the values of the displacement of the points of application of the corresponding forces relative to the center of the pallet.

The traction force created by the jet of air coming out of the inclined feed channels can be described by the expression [6]:

$$F_x = P \cdot S \cdot C_x,$$

where P — overpressure in the conveyor receiver chamber, S — the bearing surface area of the pallet, C_x — traction force coefficient.

Using the results of previous studies [6], we have:

$$C_x = \frac{16 \cdot \left(\frac{H+h}{\alpha} \right)^2 \cdot \left[1 - 2 \cdot \frac{H+h}{d} \cdot \left(1 - e^{-0.5 \frac{d}{H+h}} \right) \right]^2 \cdot \frac{\bar{\Pi}^2}{\bar{S}_1} \cdot h^2 \cdot \sin \alpha}{1 + \frac{\bar{\Pi}^2}{2 \cdot \bar{S}_1} \cdot h^2}.$$

where H — the depth of the chamber in the bearing surfaces of the pallet, d — the diameter of the feed channels.. $\bar{\Pi}$ — the ratio of the perimeter to the area of the bearing surface of the pallet:

$$\bar{\Pi} = \frac{\Pi}{S} = \frac{2 \cdot (l+b)}{l \cdot b},$$

where ℓ — the length of the bearing surface of the pallet, b — the width of the bearing surface of the pallet.

$\bar{S}_1$ — relative area of feed channels:

$$\bar{S}_1 = \frac{\pi \cdot d^2 \cdot n}{S},$$

where n — the number of feed channels in the area covered by the pallet.

The dependence of the traction force coefficient on the height of the air cushion within the studied limits is almost linear [6]. Therefore, we can suppose:

$$F_x = P \cdot S \cdot \frac{C_{x1} + C_{x2}}{2},$$

where C_{x1} , C_{x2} — the values of the traction force coefficient at the extreme points.

Then:

$$F_x = 8 \cdot P \cdot S \cdot \frac{\bar{\Pi}^2}{\bar{S}_1} \cdot \sin \varphi \cdot \left\{ \frac{\left(\frac{H+h_1}{d} \right)^2 \left[1 - 2 \cdot \frac{H+h_1}{d} \left(1 - e^{-0.5 \frac{d}{H+h_1}} \right) \right]^2 h_1^2}{1 + \frac{\bar{\Pi}^2}{2 \cdot \bar{S}_1} h_1^2} + \frac{\left(\frac{H+h_2}{d} \right)^2 \left[1 - 2 \cdot \frac{H+h_2}{d} \left(1 - e^{-0.5 \frac{d}{H+h_2}} \right) \right]^2 h_2^2}{1 + \frac{\bar{\Pi}^2}{2 \cdot \bar{S}_1} h_2^2} \right\}.$$

where h_1 , h_2 — the values of the height of the air cushion at the extreme points, φ — the angle between the vertical and the axis of the feed channel.

The lifting force that balances the weight of the pallet with the load can be determined [6]:

$$F_y = P \cdot S \cdot C_y.$$

where C_y — the lifting force coefficient:

$$C_y = \frac{1}{1 + \frac{\bar{\Pi}^2}{2 \cdot \bar{S}_1} h^2}.$$

If the gravity center of the load is shifted relative to the center of the pallet, the height of the airbag will decrease towards this shift. This will entail a change in the C_y . The nature of the dependence of C_y on h in the considered limits is close to linear [3], so:

$$C_y = \frac{C_{y1} + C_{y2}}{2},$$

where C_{y1} , C_{y2} — the values of the lifting coefficients at the extreme points.

Then:

$$F_y = F_{y1} + F_{y2} = \frac{1}{2} \cdot P \cdot S \cdot \left(\frac{1}{1 + \frac{\bar{P}^2}{2 \cdot \bar{S}_1^2} h_1^2} + \frac{1}{1 + \frac{\bar{P}^2}{2 \cdot \bar{S}_1^2} h_2^2} \right).$$

Considering the pallet with the load in equilibrium (Fig. 3), we determine the height of the air cushion at the extreme points.

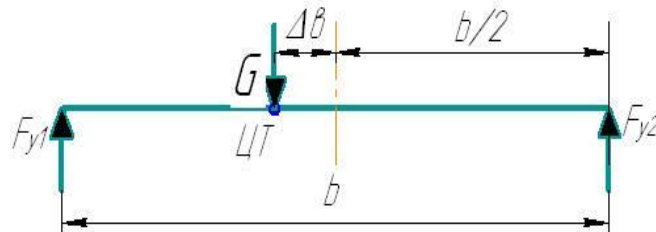


Fig. 3. Pallet with load in equilibrium

$$G \left(\frac{b}{2} + \Delta b \right) - F_{y1} \cdot b = 0, \quad F_{y1} = G \frac{b + 2 \cdot \Delta b}{2b},$$

$$G \left(\frac{b}{2} - \Delta b \right) - F_{y2} \cdot b = 0, \quad F_{y2} = G \frac{b - 2 \cdot \Delta b}{2b}.$$

Thus:

$$G \frac{b + 2 \cdot \Delta b}{2b} = \frac{P \cdot S}{2 + 4 \cdot \frac{(b+l)^2}{\bar{S}_1^2 \cdot b^2 \cdot l^2} h_1^2}.$$

From:

$$h_1 = \frac{\bar{S}_1 \cdot b \cdot l}{b+l} \sqrt{\frac{1}{2} \left(\frac{P \cdot b \cdot l}{G} \cdot \frac{b}{b + 2 \cdot \Delta b} - 1 \right)}.$$

Similar to:

$$G \frac{b - 2 \cdot \Delta b}{2b} = \frac{P \cdot S}{2 + 4 \cdot \frac{(b+l)^2}{\bar{S}_1^2 \cdot b^2 \cdot l^2} h_2^2}.$$

From:

$$h_2 = \frac{\bar{S}_1 \cdot b \cdot l}{b+l} \sqrt{\frac{1}{2} \left(\frac{P \cdot b \cdot l}{G} \cdot \frac{b}{b - 2 \cdot \Delta b} - 1 \right)}.$$

Denoting

$$\frac{G}{P \cdot S} = C_{y0},$$

we get:

$$h_1 = 0,707 \frac{\bar{S}_1 \cdot l}{1 + \frac{l}{b}} \sqrt{\frac{1}{C_{y0} \left(1 + 2 \cdot \frac{\Delta b}{b} \right)}} - 1.$$

$$h_2 = 0,707 \frac{\bar{S}_1 \cdot l}{1 + \frac{l}{b}} \sqrt{\frac{1}{C_{y0} \left(1 - 2 \cdot \frac{\Delta b}{b} \right)}} - 1.$$

The total resistance to the movement of the pallet with the load consists of:

— the resistance from sliding on the stationary surface of the conveyor;
— the resistance from friction against the guide rails, due to the displacement of the gravity center of the load relative to the center of the pallet.

The slip resistance depends on the height of the air cushion (h_1 to h_2 across the width of the pallet). The resultant is shifted relative to the center of the pallet by the value Δbw .

The height of the air cushion at the point of application of the resultant h_u can be determined from the equality of the areas bounded by the curve [6] (Fig. 4):

$$\omega = f_1 e^{-\frac{6h}{\Delta}} + 0,0008.$$

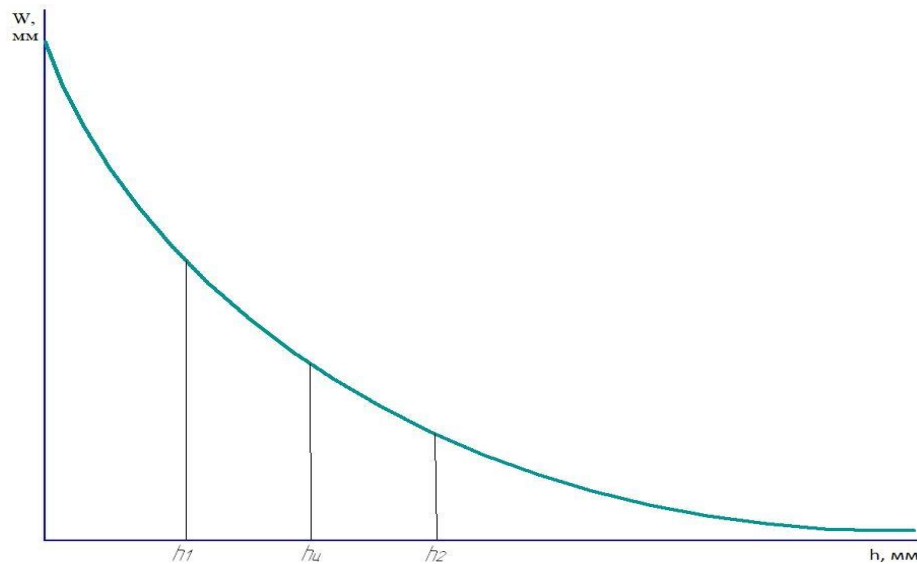


Fig. 4. Height of the airbag at the point of application

$$\int_{h_2}^{h_1} \left(f_1 \cdot e^{-\frac{6h}{\Delta}} + 0,0008 \right) dh = \int_{h_c}^{h_1} \left(f_1 \cdot e^{-\frac{6h}{\Delta}} + 0,0008 \right) dh.$$

After integration and simplification, we get:

$$\ell n h_c^2 = \ell n h_2 + \ell n h_1,$$

or

$$h_c = \sqrt{h_2 \cdot h_1}.$$

The value of the displacement of the point of application of the resultant sliding resistance forces (Fig. 5):

$$\Delta bw = b \left(\frac{1}{2} - \frac{\sqrt{h_1 \cdot h_2} - h_1}{h_2 - h_1} \right)$$

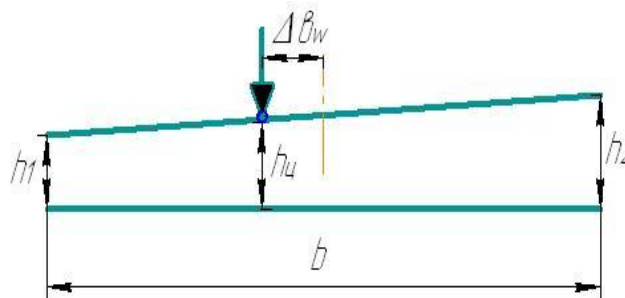


Fig. 5. The value of the displacement of the point of application

The resultant moment due to the displacement of the resultant is equal to:

$$M_w = W_c \cdot \Delta b w = G b \left(f_1 \cdot e^{\frac{6}{\Delta} \sqrt{h_1 \cdot h_2}} + 0,0008 \right) \cdot \left(\frac{1}{2} - \frac{\sqrt{h_1 \cdot h_2} - h_1}{h_2 - h_1} \right).$$

When the load is accelerated to the required speed, the inertia force is applied at the gravity center of the pallet with the load. The moment of this force relative to the center of the pallet with uniformly accelerated motion:

$$M_u = \frac{G}{g} \cdot a \cdot \Delta b.$$

This means that the resistance from the friction of the pallet on the guide rails with an off-center position of the load:

$$W_\delta = 2 \cdot \frac{f_2}{l} \cdot \left[\frac{P \cdot S}{2} \cdot b \cdot (C x_2 - C x_1) + G \cdot b \times \right. \\ \left. \times \left(f_1 \cdot e^{\frac{6}{\Delta} \sqrt{h_1 \cdot h_2}} + 0,0008 \right) \cdot \left(\frac{1}{2} - \frac{\sqrt{h_1 \cdot h_2} - h_1}{h_2 - h_1} \right) + \frac{G}{g} \cdot a \cdot \Delta b \right].$$

The condition for the movement of the pallet when the load is located off-center in the rack warehouse cell:

$$\frac{1}{C y_0} \cdot \frac{C x_1 + C x_2}{2} = f_1 \cdot e^{\frac{6}{\Delta} \sqrt{h_1 \cdot h_2}} + 0,0008 + 2 \cdot \frac{f_2}{l} \times \\ \times \left[\frac{b}{2 C y_0} (C x_2 - C x_1) + b \left(f_1 \cdot e^{\frac{6}{\Delta} \sqrt{h_1 \cdot h_2}} + 0,0008 \right) \times \left(\frac{1}{2} - \frac{\sqrt{h_1 \cdot h_2} - h_1}{h_2 - h_1} \right) + \frac{a}{g} \cdot \Delta b \right] + \frac{a}{g}.$$

Acceleration of the movement of the pallet with the load in the warehouse cell:

$$a = \frac{g \cdot \frac{l}{b}}{\frac{l}{b} + 2 f_2 \cdot \frac{\Delta b}{b}} \times \left\{ \frac{C x_1 + C x_2}{2 C y_0} - f_1 \cdot e^{\frac{6}{\Delta} \sqrt{h_1 \cdot h_2}} - 0,0008 - 2 \cdot f_2 \cdot \frac{b}{l} \times \right. \\ \left. \times \left[\frac{C x_2 - C x_1}{2 C y_0} + \left(f_1 \cdot e^{\frac{6}{\Delta} \sqrt{h_1 \cdot h_2}} + 0,0008 \right) \times \left(\frac{1}{2} - \frac{\sqrt{h_1 \cdot h_2} - h_1}{h_2 - h_1} \right) \right] \right\}.$$

It can be seen that the acceleration of the movement of the pallet with the load depends on many factors. Some of them (the dimensions of the bearing surface of the pallet and the displacement value of the gravity center) are regulated by the characteristics of the transported cargo. The coefficients of friction and the height of the surface irregularities depend on the materials from which the conveyor is made. The optimal values of the diameter and angle of inclination of the feed channels were determined earlier [4, 7]. The necessary acceleration can be obtained by varying H, and P.

Conclusion. The analysis of methods and means of mechanization and automation of transport processes in rack warehouses has shown that the use of air-cushion conveyors reduces the time for performing individual operations, simplifies automation schemes, and makes it possible to create a safe automated or easily controlled transport and warehouse system. As a result, this approach will significantly reduce capital costs and operating costs.

The results of the conducted research were used to create a methodology for determining the main parameters of hovercraft transport devices with inclined feed channels. In the case of cargo transportation with a displaced gravity center, this approach allows you to significantly expand the scope of these devices and ensure their reliable and safe operation in the storage areas of rack warehouses.

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Improvement of megacity ecological conditions with the use of a clever SmartBoxCity container-tranformer

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Introduction. The paper proposes an option for improving the environmental situation in Rostov-on-Don. That is the optimization of the way of cargo delivery to the customer using the clever SmartBoxCity container-tranformer and the Dispatcher RD program.

Problem Statement. It is necessary to improve the ecological situation of the city by reducing the number of traffic jams and the time spent in them. The task was to develop and implement technical and information support, on which the driver's ability to get up-to-date information and reduce the delivery time of products to consumers depends.

Theoretical Part. The optimization of traffic within the city must be solved using the existing traffic scheme. Due to the optimization, you can significantly reduce the number of traffic jams and the time spent in them, and, accordingly, improve the environmental situation in the city. The way how the driver gets up-to-date information depends entirely on the information support. It is proposed to use a smart folding cargo container-transformer SmartBoxCity, which includes elements of intelligent urban mobility. To optimize the delivery path in the absence of the Internet, the Dispatcher RD software product can be used.

Conclusion. The effective management, monitoring and integrated planning of the movement is carried out with the use of mobile and server applications. To improve the professional competence of students of the relevant specialties, it is proposed to use the current SmartBoxCity layout, a developed mobile application and a computer program for optimizing the delivery path.

Keywords: ecology, smart container, mobile application, optimization of the cargo delivery route, computer program.

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Introduction. Currently, the transport channels of various goods are the main arteries of the economy. In most countries, 70-80% of national economic goods are transported by road, which is due to the high speed and maneuverability. Environmental pollution is caused by many factors, but car exhaust gases cause the greatest harm. Every year, hundreds of millions of tons of harmful substances enter the atmosphere with exhaust gases: sulfur dioxide, hydrocarbons, nitrogen oxides and many other pollutants. Fuel and a non-optimal approach to cargo delivery are the first in the list of factors that affect the environment and the cost of cargo transportation.

Problem Statement. It is necessary to develop technical and information support for the transport system of cargo transportation, which will allow you to effectively manage, control and plan the movement of transport and material flow. In this article, to implement the optimization of cargo delivery, it is proposed to use the SmartBoxCity smart folding cargo container-transformer, which includes elements of intelligent urban mobility and wireless communication technologies of the Internet of Things, as well as the software product Dispatcher RD.

Theoretical Part. As shown by numerous environmental studies conducted in recent years, there is a sharp increase in emissions of pollutants into the atmosphere. The greatest contribution to atmospheric pollution is made by road transport, which determines the undoubted relevance of the presented development [1].

Table 1 shows the main types of fuel and pollution from road transport. Table 2 shows the composition of the exhaust gases of gasoline and diesel fuel.

Table1

Types of pollution from the use of road transport

Fuel type	Type of pollution	Usage
Gasoline	Hydrocarbons, carbon monoxide, nitrogen oxides	Cars, buses, planes, motorcycles
Gasoline (with oil)	Hydrocarbons, carbon monoxide, nitrogen oxide, solids	Motorcycles, auxiliary motors
Ligroin	Nitrogen oxides, solid substances	Buses, tractors, cars, trains

Table 2

Exhaust gas composition

Exhaust gas composition	Gasoline	Diesel	Toxicity
	Content by volume, %		
Nitrogen	74.0–77.0	76.0–78.0	nontoxic
Oxygen	0.3–8.0	2.0–18.0	nontoxic
Water vapor	3.0–5.5	0.5–4.0	nontoxic
Carbon dioxide	5.0–12.0	1.0–10.0	nontoxic
Carbon monoxide	0.1–10.0	0.01–5.0	toxic
Non-carcinogenic hydrocarbons	0.2–3.0	0.009–0.5	toxic
Aldehydes	0–0.2	0.001–0.009	toxic
Sulfur oxide	0–0.002	0–0.03	toxic
Soot, g/m ³	0–0.04	0.01–1.1	toxic
Benzopyrene, mg/m ³	0.01–0.02	до 0.01	carcinogen

To improve the environmental situation in Rostov-on-Don, the regional authorities plan to form a transport ring around the city, which will allow bringing transit transport outside the city. However, inside the city, the problem has to be solved using measures to optimize the existing traffic pattern. To clean the air from exhaust gases and improve the environment, it is necessary to reduce the standing time and exhaust emissions in traffic jams. The delivery time of the products and the possibility of getting the driver up-to-date information depends largely on the information support. Figure 1 shows the different states of the SmartBoxCity smart folding cargo container-transformer.



a)



b)



c)

Fig. 1. Folding cargo container: a — FCC in the assembled state;
b — preparation for loading; c — FCC is ready for loading

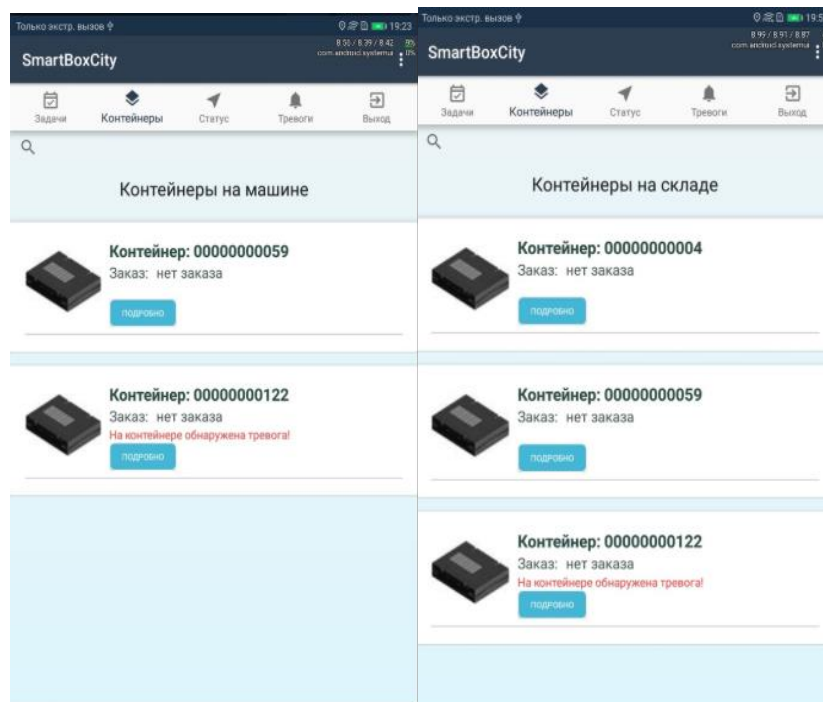
The hardware performs the functions of transporting piece, bulk and liquid cargo; it is automatically transformed (folding/unfolding); the weight of the container and the cargo being moved is measured; the location in space and time is tracked. The door mechanism can withstand at least 30 cycles. The container itself does not exceed the established norm. The efficiency of storage/opening is 50 cycles [2, 3]. For the software and hardware, a project for the electrical equipment of the container has been developed, including two electrical control cabinets with the control equipment.

A mobile Web application for users has been developed. It integrates with other corporate systems [4, 5]. The Web application functions:

- identification of the customer and the cargo;
- monitoring the location of the container.

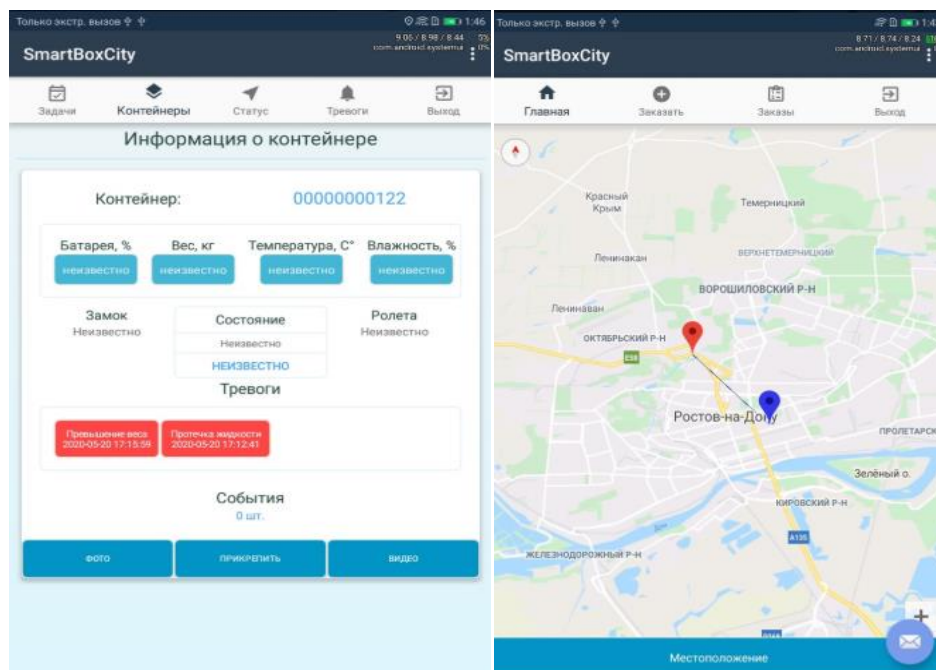
The cargo is identified by type (piece, bulk, liquid) and mass-volume characteristics. Virtual administration is performed remotely. The weight and volume of the cargo, the temperature and humidity inside the container, and the opening/closing that indicates depressurization are measured by built-in sensors. The server includes a switching server for collecting, processing, storing and relaying data. The switching server ensures the smooth operation of the system as a whole. Drivers can monitor and dispatch equipment using a mobile app and a Web interface [6-8].

Mobile application and Web interface. The software also includes mobile applications written in the Python programming language. These applications constantly interact with a central Web server to transmit and receive data. The driver is provided with various information, including two lists of containers: containers in the car (Figure 2 a) and containers at the warehouse (Figure 2 b). For each of the container, you can view a more detailed information (battery charge, temperature, etc.) (Fig.2 c, 2 d).



a)

b)



c)

d)

Fig. 2. The menu of the mobile application: a — container in the car;
b — container at the warehouse; c — information about the container;
d — location of the container

The software part of the container management consists of the server and client parts. The server part of the solution is a Web site — a server for collecting, processing, relaying data and transferring it to the database. The web service is an environment for interaction between the customer, the delivery driver and the SmartBoxCity hardware. To log in to the Web service you need a browser and a mobile application, in which users, depending on their rights, get access to the corresponding functionality for configuring and managing the SmartBoxCity system.

If there are several cars with empty containers on the route, moving next to each other, then at a certain place in the parking lots, they can be reloaded from car to car. At the same time, logistics optimization is carried out to free one of the cars from empty containers. The joint operation of vehicles when loading stacked containers into the body of one of the vehicles is an element of the so-called "caravan movement" in optimizing cargo transportation.

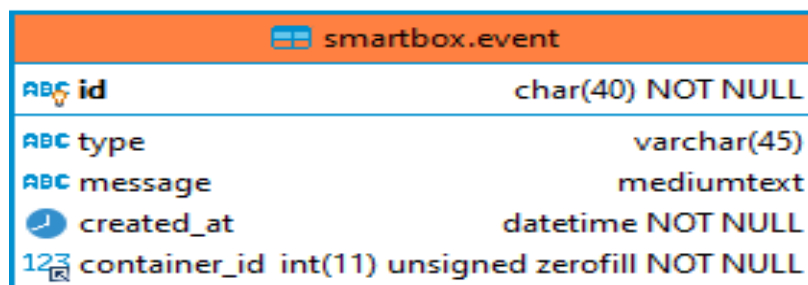
Various tables are designed to store information about the events that occurred on the container. Tables 3 and 4 and Figures 3–5 show the structure of the EVENT and ALARM tables and the structure of the alarm messages on the container.

Table 3

EVENT table structure

EVENT table	
id	event identification number
type	event type
message	event message
created_at	event date and time
ontainer_id	reference to the FCC ID

Fig. 3 shows the structure of tables for storing information about the container events.



smartbox.event	
ABC id	char(40) NOT NULL
ABC type	varchar(45)
ABC message	mediumtext
🕒 created_at	datetime NOT NULL
123 📦 container_id	int(11) unsigned zerofill NOT NULL

Fig. 3. The structure of tables for storing information about the container events

Table 4

ALARM table structure

ALARM- table	
id	alarm identification number
message	alarm message
alarm_type_id	alarm type number
name	alarm name
persistent	auto fix
alarm_status	alarm status
acknowledged	notification confirmation

Figures 4 and 5 show information about the container alarms.

ID	Состояние	Датчики	Ролета	Замок	События	Тревога
00000000321	Разложен	Батарея, %: 0.0	Открыта	Закрыт	24 штуки	Признать Протечка жидкости 19:22 04.08.2020
		Вес, кг: 0.0				
		Температура, C°: 85.0				

Fig. 4. Information about alarms on the container

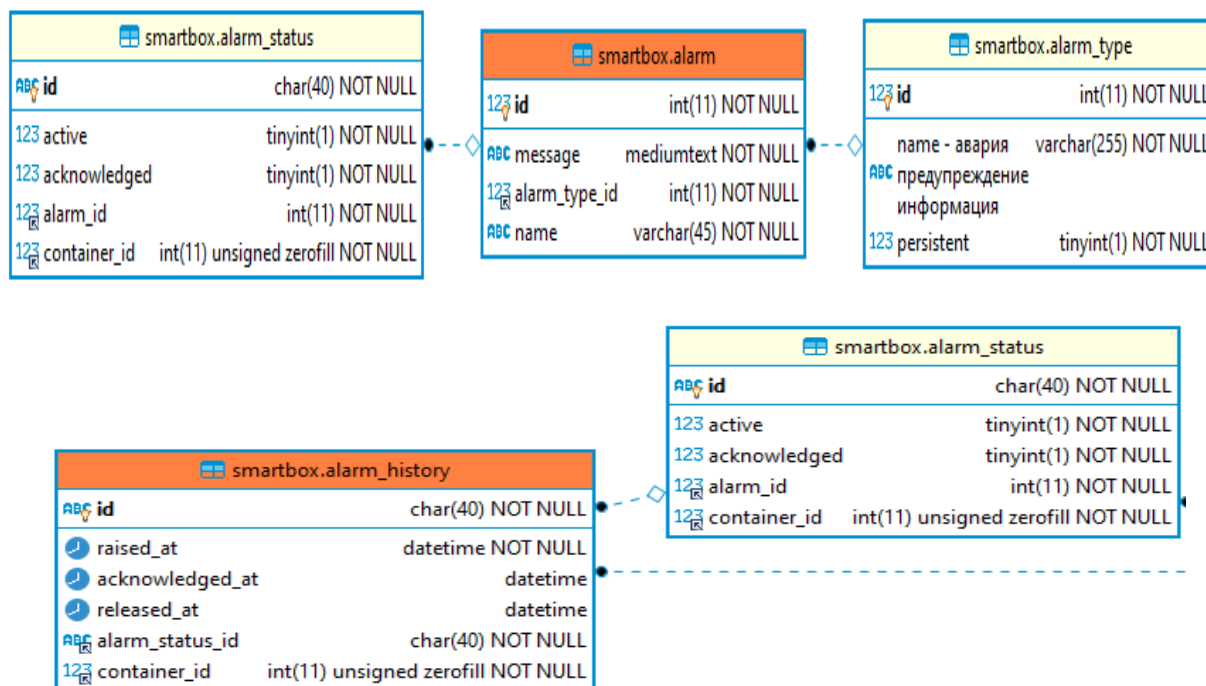


Fig. 5. Table structure for storing the container alarm information

The developed software application communicates with Yandex, the router. To optimize the delivery path without the Internet, the software product Dispatcher RD can be used.

Numerous field observations and mathematical calculations of transport characteristics based on the method of electrodynamic modeling served as the basis for the creation of the Dispatcher RD software product [9–11]. The article [11] shows the work of the program on the example of delivery of FCC from the manufacturer in Novocherkassk to the Rostov-Tovarny station. This program will allow the system to work without the Internet and can be used for educational purposes

Figure 6 shows the view of the initial menu of the Dispatcher RD program: selection of the city, departure point, and intermediate points. You should select the type of the map, the area of cargo dispatch; determine the intermediate points and the delivery point. The example of the FCC delivery from the point of manufacture to the Rostov-Tovarny station shows the initial menu of the program (Fig. 6). The map of the city of Novocherkassk is presented. In the menu window, you must specify the departure point and intermediate delivery points of the FCC, if there are any. Figure 7 shows an example of calculating the optimal path for the FCC delivery from the place of manufacture (Novocherkassk) to the Rostov-Tovarny station with the indication of intermediate points and the built route.

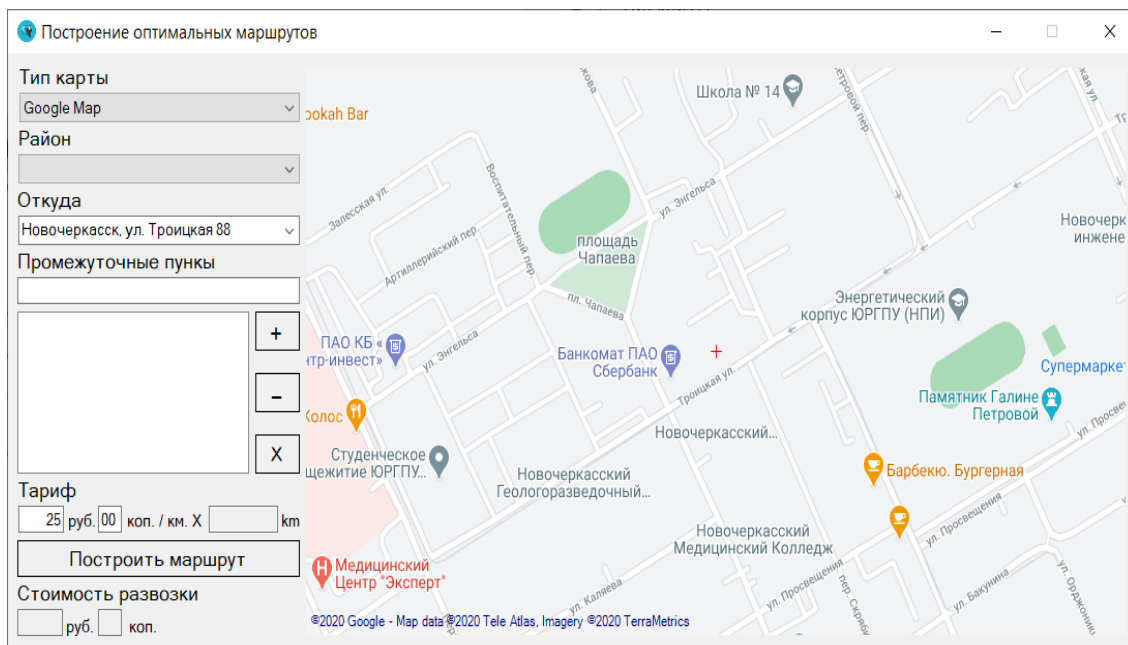


Fig. 6. View of the program's start menu

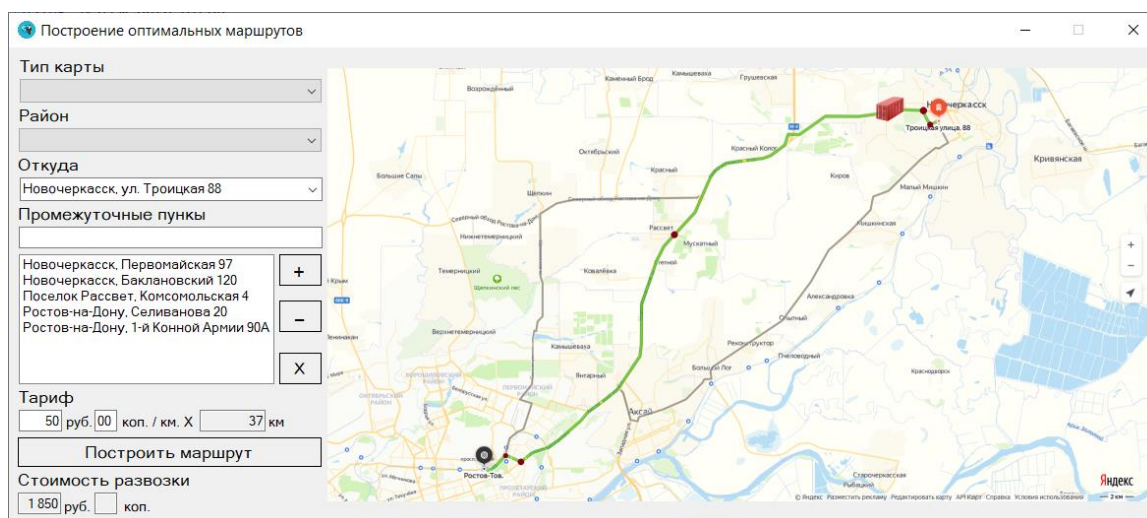


Fig. 7. The built route

Conclusion. The competition between the transport companies is quite big. Saving fuel and travel time provides additional opportunities to improve the performance of the transport company. The FCC, software and the mobile application for managing the FCC are available for purchase by transport companies. The managed SmartBoxCity mockup, a mobile application, and a software package for modeling the optimal route can be used by specialized secondary and higher educational institutions for educational purposes. The reliability of the obtained results was confirmed by conducting full-scale tests on a special stand and transport using mockup, and then prototype samples of the SmartBoxCity transformer container. An exhibition copy was made — a working model of a vehicle in the form of a car with a manipulator and two SmartBoxCity transformer containers, which will be shown at exhibitions to attract potential consumers. Agro-industrial group of companies Yug Rusi, Rostov-on-Don, showed some interest to the product to use SmartBoxCity in logistics transportation for its own needs (Yug Rusi is the world leader in the production and sale of bottled vegetable oil, sunflower seeds, grain and flour).

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Analysis of methods for processing and using by-products of the technological process of asphalt concrete component manufacturing

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Introduction. Currently, the problem of disposal and recycling of industrial waste is extremely relevant. The article analyzes the economically feasible and environmentally friendly ways of the processing or using waste generated during the production of the asphalt concrete component — enriched mineral filler.

Problem Statement. The aim of the study was to find the most economically feasible and environmentally friendly ways to process or use waste generated during the production of enriched mineral filler at one of the enterprises of the Rostov region.

Theoretical Part. The paper considers the composition of the enriched mineral filler as the main product of production and a source of by-products, the technological process of its manufacture, as well as the composition of the resulting by-products to be disposed. Based on the results of these studies, the assessment of probable ways of waste disposal was performed and the optimal method of recycling was selected.

Conclusion. The choice of the most appropriate method of waste disposal from the production of mineral filler allows you to reduce the total amount of waste at the enterprise and significantly reduce the negative impact of the enterprise on the environment. To implement the proposed technology of mineral waste disposal, the relevant technical conditions and regulations are being developed.

Keywords: industrial waste, recycling, mineral filler, environmental safety.

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Introduction. The problem of recycling municipal and industrial waste is urgent and acute now as never before. Many industrial enterprises are gradually switching to closed production cycles, actively developing low-waste and non-waste technologies in order to reduce the burden on the environment and improve the situation in the field of waste management [1-5]. In the village of Zhirnov, Rostov region, there is a production enterprise Karbonat AO, which actively implements environmentally safe production cycles in its economic activities, while focusing on modern alternative methods of recycling the resulting waste [6].

Problem Statement. The enterprise Karbonat AO has a technological line for the production of mineral filler, which is then subjected to enrichment, and then used in the manufacture of asphalt concrete and other road surfaces. The implementation of this production process is accompanied by the release, primarily into the atmospheric air, of a number of by-products officially classified as industrial waste, which are subject to mandatory disposal [7-9]. The purpose of this work was to find the most economically feasible and environmentally friendly ways to process or use the waste generated during the production of the enriched mineral filler at Karbonat AO.

Theoretical Part. The solution to these tasks is in the study of the mineral-enriched filler as the main product of production and the source of the by-products formation, the technological process of its manufacture, and composition of the formed by-products (waste), recyclable. The results of these studies are the basis for evaluating the likely ways of waste disposal and selecting the most appropriate one.

The raw material for the production of the enriched mineral filler at Karbonat AO is a crushed natural material - limestone of the 0-5 mm fraction extracted from an open pit. Limestone is a sedimentary rock consisting mainly of calcite CaCO_3 , which includes CaO (56%) and CO_2 (44%) [7, 8].

Limestone has the following physical and mechanical properties [7]:

- average density — 2.6–2.75 t/m³;
- water absorption — 0.0–2.07 %;
- porosity — 0.37–4.76 %;
- the limit of compressive strength in dry state — 57.6–145 kPa;
- compressive strength in the water-saturated state — 51.4–139.8 kPa;
- degree of fragmentation — 1.733.

In the process of mineral filler enrichment, petroleum bitumen is added to it — a combustible solid substance that is obtained by oxidation of tar (a residual product of oil refining) with atmospheric air. In addition, during enrichment, an adhesive additive (in other words, a surface active compound) is added to the mineral filler, which is a dark brown homogeneous mobile mass, non-volatile, non-explosive and non-toxic [10]. The addition of surface active compounds or materials including them to the filler is made in order to improve the performance properties of the mineral filler and, as a result, extend the service life of the road surface, the component of which the filler becomes in the future [11].

In general, the technology for the enriched mineral filler production consists of drying the original natural raw materials (limestone), crushing it, screening out the desired fraction, subsequent application of petroleum bitumen, surfactants and thorough mixing of the resulting mixture.

It is at the stage of crushing natural limestone on the crushing and sorting equipment that limestone dust is formed, which enters the air environment and is captured by the dust and gas cleaning unit located in the crushing department and accumulates in its receiving hopper. In accordance with the Federal Classification Catalog of Waste (FCCW) [12], the captured dust is classified as "Waste of limestone, dolomite and chalk in the form of powder and dust of low hazard". This waste is accumulated on the territory of Karbonat AO in special containers and is subject to further export to the disposal sites.

It should be noted that a similar situation occurs when grinding sandstone is used as a raw material for the production of crushed stone at the enterprise in question. When implementing this technology, waste is collected in the receiving hopper of the dust and gas cleaning plant, which is classified in accordance with the FCCW as "Crushed stone gas cleaning dust" [12]. After removal from the hopper, this dust also accumulates on the territory of the enterprise with subsequent removal for disposal [1, 7].

Conclusion. The disposal of the above-mentioned types of by-products (waste) of the production of asphalt concrete components can be carried out in several ways.

The simplest and most often used way in such a situation is the removal of waste with its subsequent disposal at a specialized landfill. This way is currently used by Karbonat AO, while paying for the disposal of waste. The following methods of disposal of these wastes can be an alternative to disposal [7, 13]:

- separation of useful fractions during waste sorting and their further processing;
- secondary consumption (at the same enterprise in other production cycles);
- re-use in the same production.

The proposed disposal options will reduce the total amount of waste generated at the enterprise and received at landfills, and, of course, will give a tangible economic effect to the enterprise [14]. Thus, the secondary consumption and / or reuse of limestone and crushed stone dust will allow Karbonat AO not to pay for the disposal of waste at the

landfill, which is currently about 18,800 rubles per year: the volume of formation of these wastes is about 27 tons and 20 tons per year, respectively, the fee for the disposal of 1 ton of waste at the landfill is 400 rubles.

Thus, in order to reduce the volume of waste from the production of enriched mineral filler and reduce the harmful impact on the environment, the company can recommend the waste classified as "Low-hazard limestone, dolomite and chalk waste in the form of powder and dust" and "Crushed stone gas cleaning dust" to be used as secondary raw materials, adding them as additives to the main commercial product — the enriched mineral filler. The origin, chemical composition and other qualitative characteristics of these wastes indicate that their addition will not affect the properties of the resulting mineral filler and will not worsen its quality. In addition, the recommended reuse of limestone and crushed stone dust in the same production as secondary raw materials (47 tons per year) will give Karbonat AO an additional economic benefit of about 30,550 rubles per year, since the initial raw materials for the production of mineral filler (natural limestone) are purchased by the company at an average price of 650 rubles per 1 ton. It follows that the total economic effect of the implementation of the proposed solutions at 2020 values will be approximately 49,350 rubles per year (18 800 + 30 550).

To use these types of waste in the production of the enriched mineral filler, it is necessary to develop technical specifications (TS) and technical regulations (TR) for mineral filler, which will include the above-mentioned waste. The first step in this direction is the study of various technical specifications and technical regulations, on the basis of which it will be possible to develop similar documents for mineral filler with the proposed modernized composition in the future [10].

Thus, in the course of the work, the analysis was carried out of cost-effective and least dangerous to the environment methods for recycling by-products of the manufacture of the asphalt concrete component — the enriched mineral filler. The choice of the most appropriate method of waste disposal will reduce the total amount of waste at the enterprise, as well as significantly reduce the negative impact of the enterprise on the environment. To create the technology for the disposal of the considered mineral waste, it is necessary to develop appropriate technical specifications and regulations.

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V. V. Ozeryanskaya — formulation of the main concept, goals and objectives of the study, analysis of the research results, formulation of conclusions; A. A. Repinskaya — definition of research objects, preparation of the theoretical part; R. R. Lazurenko — analysis of literary sources, revision and correction of the text; M. Yu. Seregin — consultations on technology and regulatory documents.